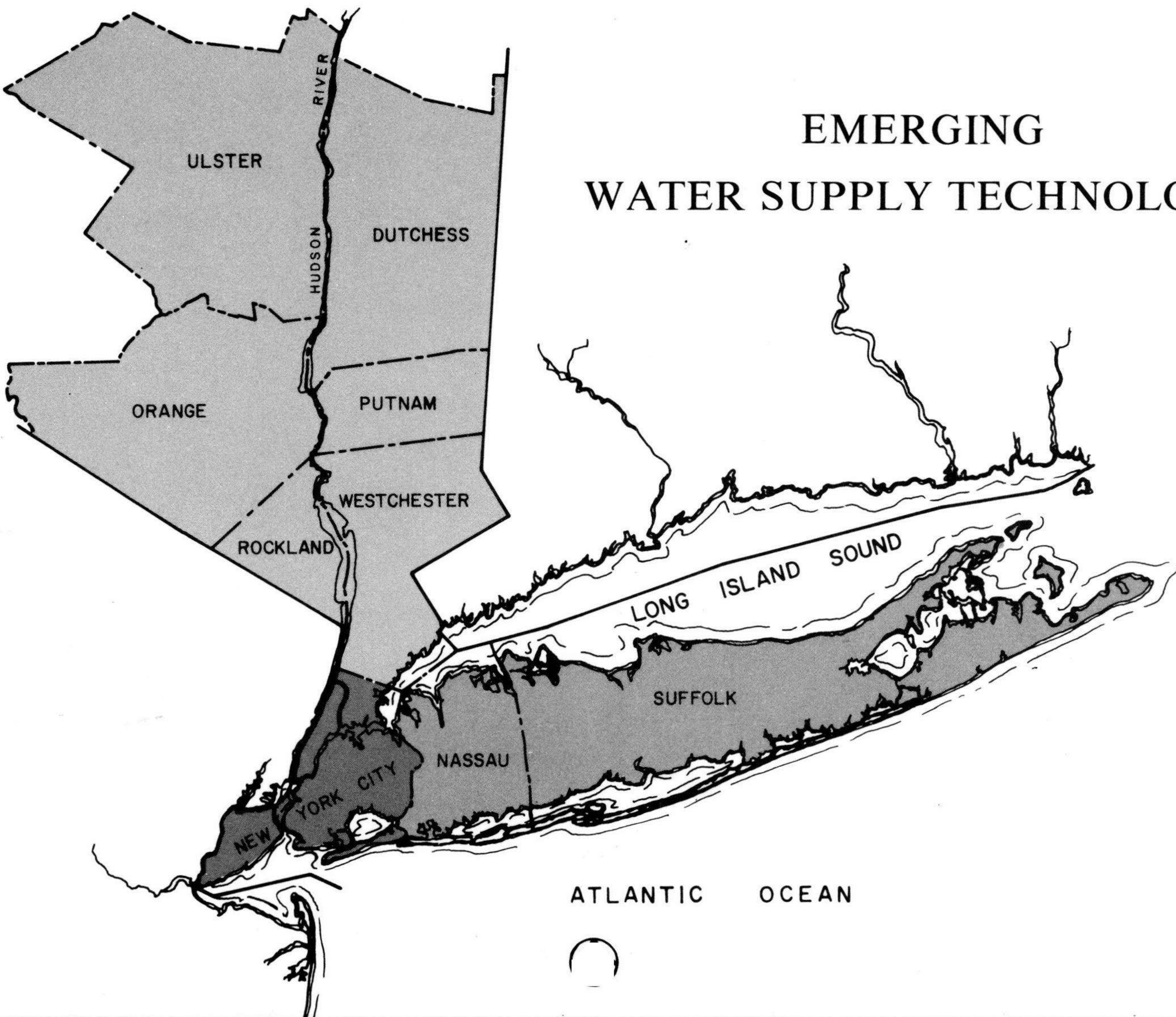
Temporary State Commission on the Water Supply Needs of Southeastern New York

EMERGING WATER SUPPLY TECHNOLOGY



March 1, 1973

Albany, New York

Temporary State Commission on the Water Supply Needs of Southeastern New York

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FOR RELEASE: A.M.s MONDAY, MARCH 26, 1973

DESALINIZATION, WEATHER MODIFICATION, RECYCLING AND REUSE NOT THE ANSWERS FOR MEETING WATER SUPPLY NEEDS

NEW YORK, March 25 -- Desalinization, weather modification, and reuse do not offer any immediate hopes of meeting the water supply needs of the southeastern New York region, according to a report released yesterday by E. Virgil Conway, chairman of the Temporary State Commission on the Water Supply Needs of Southeastern New York.

The report entitled "Emerging Water Supply Technology" explored the three methods as possible ways of meeting the water supply deficits which have been predicted for the future.

"Based on excessive costs, siting problems, and brine disposal, desalinization is not recommended for use in southeastern New York," the report said. It recommended that research in this area be intensified by the federal government.

On weather modification the report found, "Based on the uncertainty in seeding clouds, the small increase in available water, and the need to construct more reservoirs, weather modification is not recommended in southeastern New York as a means of increasing water supply."

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Direct recycling and reuse, a connection between a wastewater system and a water supply system, was rejected. "Direct reuse of reclaimed wastewater is not recommended as a means of supplementing public water supply because of the danger to consumers. At this point in time direct reuse represents an uncalled-for risk. Existing advanced waste treatment processes are not able to ensure complete removal of toxic organics or viruses," the report pointed out.

Indirect reuse via the common use of a stream for water supply and wastewater disposal is now utilized and is acceptable with appropriate safeguards, the report said. Another form of indirect reuse is by recharging of groundwater with treated wastewater. This offers real possibilities on Long Island for water supply augmentation. However, deep well recharge has not been successful as yet. Surface basin recharge appears to offer the best possibility providing advanced waste treatment is utilized including nitrogen removal. On this means the report concluded that additional research is needed both on the technical and economic aspects of groundwater recharge of treated wastewater effluents before it can be depended on as an acceptable means of water supply augmentation.

The Temporary State Commission on the Water Supply Needs of Southeastern New York was named by Governor Rockefeller and legislative leaders in 1970 to determine the long range water supply needs of the metropolitan area including New York City and the eight suburban counties of Ulster, Dutchess, Orange, Putnam, Rockland, Westchester, Nassau and Suffolk, evaluate specific alternatives, both technical and managerial, to meet needs, and make recommendations based on needs, cost, administration, and environmental impact.

The commission has been conducting management and technical studies and has been holding extensive conferences with local officials, state agencies, public interest groups and federal and interstate agencies. This is its sixth interim report.

The commission is scheduled to make its final report to Governor Rockefeller and the Legislature by December 15, 1973 and is in the process of analyzing its findings and formulating specific recommendations to offset the predicted water deficits disclosed in the "Scope of Public Water Supply Needs" report of the Commission.

Mr. Conway is Chairman of the Board and President of the Seamen's Bank for Savings, New York City.

TEMPORARY STATE COMMISSION
ON THE
WATER SUPPLY NEEDS
OF
SOUTHEASTERN NEW YORK

EMERGING WATER SUPPLY TECHNOLOGY

March 1, 1973
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TEMPORARY STATE COMMISSION

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OF

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MARCH 1, 1973

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Governor

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Temporary President of the Senate

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Speaker of the Assembly

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FOREWORD

There is a great deal of interest in unique and imaginative approaches for supplying the future water needs of southeastern New York. This report investigates new technological methods which might be used to furnish needed quantities of fresh water.

From a review of current literature, the state-of-the-art and feasibility of desalination, induced rainfall, reclamation and reuse, and recharge are analyzed. To encourage an exchange of information and to get the advantage of their expertise, portions of this report were sent to the Office of Saline Water, United States Geological Survey, Environmental Protection Agency, Corps of Engineers (NEWS), New York State Department of Environmental Conservation, New York State Atomic and Space Development Authority, and the New York State Department of Health. The comments and suggestions from these agencies were included in the preparation of this report.

E. Virgil Conway

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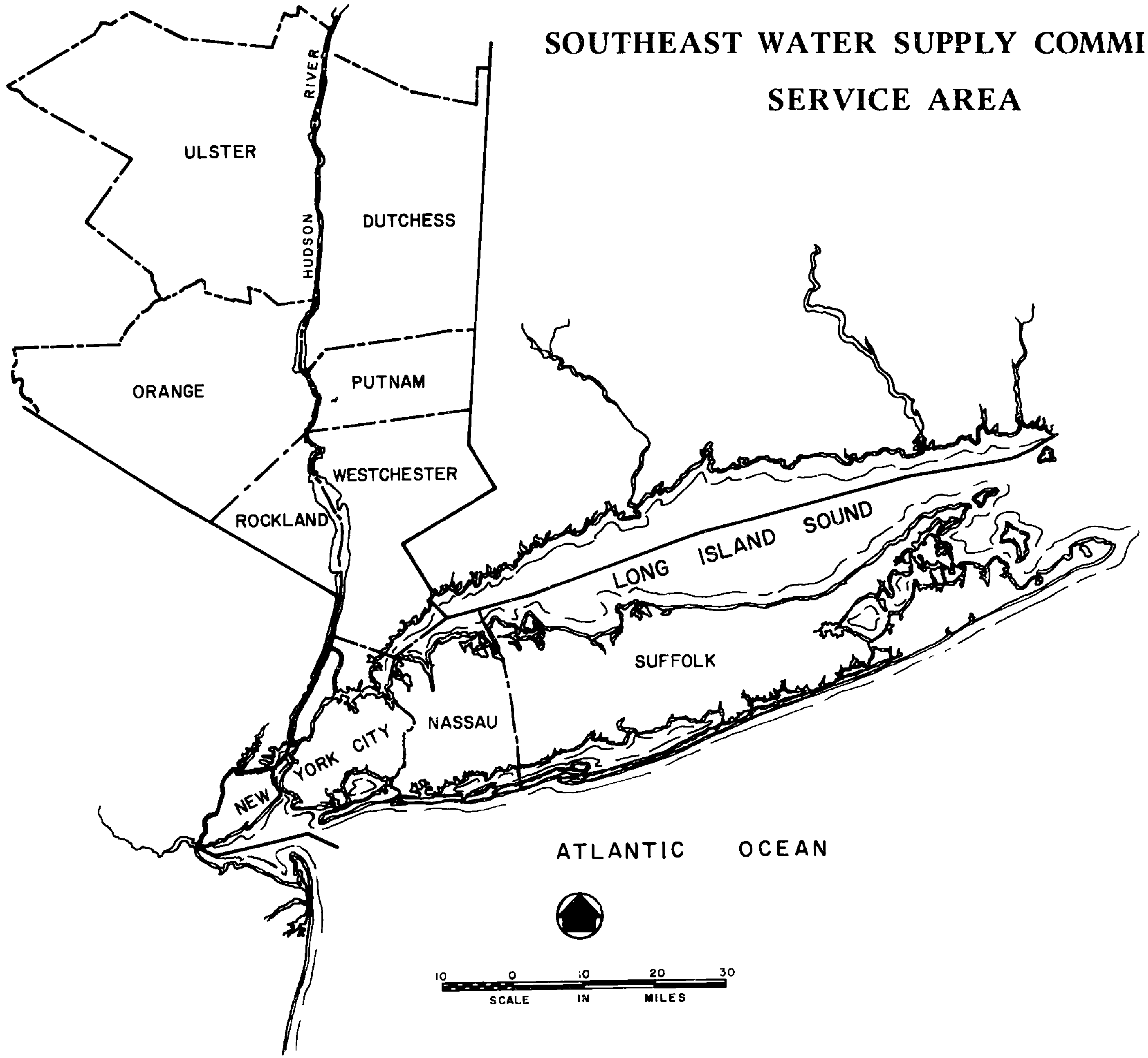


SUMMARY OF EMERGING WATER SUPPLY TECHNOLOGY

SUMMARY OF DESALINATION IN SOUTHEASTERN NEW YORK

There are many processes for converting saline water to fresh water, all of which use either physical, chemical or electrical means. The oldest method having the greatest amount of production experience is distillation and its variations. Electrodialysis is a process which has some pilot plant experience. Electrodialysis is not a total removal process, but removes only a portion of the dissolved salt. Reverse osmosis is also a partial salt reduction process which has very recently been developed for commercial applications. It is a promising process and may receive much of the research and development emphasis. Freezing is a method for desalting which has some potential. There are other processes for desalting which have been considered but they are either of dubious reliability or are not economically competitive. A description of the processes is given in the text.

Although there has been a recent increase in desalting plant construction, there is presently a world-wide total on-line capacity of about 250 million gallons per day. Virtually all of this is from distillation plants, although there are 44 electrodialysis, three reverse osmosis, and three freezing plants. In 1971, the largest plant in operation had a capacity of 7.65 MGD and the largest in the United States had a capacity of 2.62 MGD.

One of the frequently underestimated problems of desalting is the disposal of the brine of plant effluent. Disposal of the heated brine in such a manner as to minimize environmental damage may involve a considerable cost. This problem is somewhat abated in dual purpose plants.

A dual purpose plant is one which includes electrical power generation and water desalting in one operation, gaining some economies. A dual purpose plant has been considered for the New York area but has not progressed beyond the planning stage.

The biggest problem with the planning of dual purpose plants could well be the choice of a site. Present safety regulations require nuclear plants to be located away from densely populated regions. However, the costs of water and power transport would make sites closer to population centers more attractive. Resolution of these conflicting considerations may prove quite difficult.

Estimates developed in three reports were used to develop an overview of costs at the current state of the art of desalting. These costs include fixed, capital, and operating costs, but do not include cost of brine disposal. For a dual purpose nuclear-fueled distillation plant operated 85 per cent of the time with a 300 MGD capacity, the water costs are estimated to be about $450 per million gallons of fresh water. For a single purpose nuclear-fueled distillation plant of the same capacity the costs are estimated at $501 per million gallons of fresh water. Costs from reverse osmosis plants are expected to be even greater, ranging up to $685 per million gallons for a 300 MGD plant. For a 300 MGD, single purpose nuclear-fueled plant which is operated only 30 per cent of the time, or three years out of ten, the cost per million gallons climbs to $1,216. It should be recognized that these estimates are tentative as they are based on experience from rather small plants. Furthermore, these cost estimates should be increased to include environmental and brine disposal costs.

Based on excessive costs, siting problems, and brine disposal, desalting is not recommended for use in southeastern New York.

SUMMARY OF WEATHER MODIFICATION TO AUGMENT WATER SUPPLY

Precipitation formation may be considered to occur in two steps. First, a cloud of tiny droplets must form, and secondly, many cloud droplets must combine to form a raindrop size particle. Weather modification techniques enchance the formation of a large drop from cloud droplets. Consequently, weather modification can only be applied in situations where there are clouds.

The type of cloud influences the success of precipitation modification. Increases in precipitation on the order of 10 per cent have been observed for cloud seeding over the high mountains of the western United States. Little success has been achieved by cloud seeding in the northeastern United States, however.

Successful seeding of convective and cyclonic cloud systems has not been consistent.

There are many unresolved legal problems which can complicate attempts to modify the weather. These include the lack of laws and statutes controlling cloud seeding, liability cases resulting from floods, destroyed crops, etc., and the problem of who owns any increased precipitation.

The feasibility of using weather modification to increase water supply in New York State is very remote. Even if cloud seeding could produce a 10 per cent annual average precipitation increase (which it cannot), only about 120 MGD additional water would become available from the Delaware Watershed. This falls far short of meeting the future water needs of the region. During dry years when additional water is needed most, the increase would be much less than 120 MGD. It would become necessary to construct additional reservoirs to store induced rainfall from wet years for use during dry years. But this defeats one of the major advantages of weather modification - the possibility of eliminating any need for new reservoirs.

Based on the uncertainty involved in seeding clouds, the small increase in available water, and the need to construct more reservoirs, weather modification is not recommended in southeastern New York as a means of increasing water supply.

SUMMARY OF WASTEWATER RECYCLING AND REUSE

Recycling and reuse are dependent to a great extent on available technology. Treatment processes are needed to furnish any desirable quality of finished water. Consequently, an investigation into the presently available advanced wastewater treatment processes, both technically and economically, is necessary.

Potentially, wastewater can be recycled and reused for a variety of purposes. This report is concerned with recycling and reuse for public water supply purposes. The three major elements of concern in wastewater recycling and reuse are covered in the following sections of this report. These are:

- Advanced Wastewater Treatment Processes
- Direct Reuse
- Indirect Reuse

Direct reuse is delivery of treated wastewater directly to the point of use. Indirect reuse is delivery of treated wastewater into ground or surface waters which are eventually used for public water supply purposes.

Advanced Wastewater Treatment Processes

Two alternative methods exist by which sewage can be reclaimed. Processes such as distillation and reverse osmosis remove essentially all contaminants in a single step. For a variety of reasons, these processes do not appear practical at the present time. The second alternative is to further purify the effluent from existing secondary level sewage treatment plants by a series of advanced waste treatment (or tertiary) processes. Since five general types of contaminants remain in sewage discharged from present-day plants, specific processes have been developed or are being developed to remove each contaminant.

Suspended and colloidal solids constitute the first group of impurities to be removed. These particles can be removed by coagulation and sedimentation followed by filtration.

The second category of impurities are plant nutrients: phosphate, nitrate, and ammonia. Processes to remove nutrients are available. Phosphate can be removed by chemical precipitation. Nitrate and ammonia can be removed by nitrification-denitrification, although this process is very new and its reliability in treating a water destined for reuse is questionable.

Equipment to remove dissolved minerals, the third contaminant, is commercially available. Electrodialysis appears the most economical process at this time. Its operation can be regulated to remove any percentage of inorganics required.

Nonbiodegradable organic matter can be largely removed through activated carbon adsorption. It is not presently known if any of the organic substances remaining after treatment could be harmful, even when present in very small concentrations. Additional research is needed before users can be assured that the organics present in reclaimed water will not adversely affect their health.

The last contaminant consists of pathogenic organisms, particularly bacteria and viruses. Chlorination can be used to effectively control all the bacteria in reclaimed wastewater. However, a small number of viruses remain even after chlorination and present a health hazard with the direct reuse of wastewater. Until methods which can easily detect and enumerate viruses are developed, reclaimed water cannot be considered absolutely safe for human consumption by direct reuse.

Advanced waste treatment is in an early stage of application. Problems include variation of input water, the need for a fail-safe system, the effect of small concentrations of contaminants that cannot be removed, the persistence of viruses through the treatment processes, the need to scale up processes and questionable economics. In spite of these problems, continued development is expected so that eventually it should be possible to produce a finished water from wastewater to meet the most exacting specifications. This is not the case at present and probably will not be for some time to come.

Direct Reuse - Treated Wastewater

Direct reuse of reclaimed wastewater for public water supply would require:

1) Construction of an advanced wastewater treatment plant at an existing secondary sewage plant.
2) Delivery of the reclaimed wastewater by
   a) direct injection into the nearest water supply main, or
   b) transmission to the head of the system.

Direct injection means that the treated wastewater would be immediately available for use with limited dilution or blending. By transmission to the head of the system, the opportunity would be present to blend the treated wastewater with natural water to some desired dilution level. The greatest concern is the safety of the consumer. The water furnished must be pathologically safe and free from toxic material. Furthermore, it should be physically attractive and palatable. These matters depend on the contaminants found in the reclaimed water, and the reliability and efficiency of the advanced waste treatment processes used for removal.

Processes to remove suspended and colloidal solids are available and operate efficiently and effectively. Phosphates can also be removed. Ammonia and nitrate removal processes are available and appear promising, although their reliability remains to be proven.

Dissolved inorganics as a group do not pose any significant threat, and removal procedures are available to reduce large concentrations. The one area of concern involves substances, such as lead, mercury and arsenic, which are toxic even in the extremely small doses remaining after treatment. The best way of controlling these harmful substances is by eliminating their source. Since they are often found in industrial discharges, industrial wastewater should be sewered separately and not allowed to reach the reclamation plant. This would largely eliminate many of these toxic materials from the reclaimed water.

These three categories of contaminants, suspended and colloidal solids, nutrients and inorganics, do not pose any large threat to the health of the users of wastewater provided:

1. Existing removal processes are rigidly applied.
2. New processes such as nitrification-denitrification prove reliable and effective.
3. Disposal of small amounts of toxic inorganics into existing sanitary sewers is prohibited.

The remaining two categories of contaminants, refractory organics and pathogenic organisms, do pose a significant health threat even if the above conditions are met. It is not possible to remove all organics using activated carbon. The composition and toxicity of the remaining fraction is not known. <u>Studies concerned with the identification and toxicity or organic compounds not removed by activated carbon have hardly begun</u>.

Direct recycling of water containing viruses could result in contamination of the water supply. Water is not currently important in transmission of viral diseases as most infections result from other types of transmission. This is most likely due to rigorous water sanitation practices, which include acquiring raw waters with a low viral load. There is a definite lack of knowledge in detecting, identifying and enumerating viruses in water samples. Until these information gaps are filled, it is impossible to precisely predict the potential hazards of viruses involved in wastewater reuse. It is generally agreed that presently known treatment processes do not remove all the viruses. It has been estimated that approximately 1200 people would be infected daily by viruses from ingesting reclaimed water from a 100 MGD source. These people could then, in turn, spread their viruses to others throughout the community by personal contact.

The fact that renovated wastewater meets or exceeds all limits recommended by the Federal Drinking Water Standards does not mean that particular water is safe for consumption. Implicit in these Standards is the assumption that the best source of water supply should be used. This means that any source of water should be essentially free of viruses.

The reliability of wastewater treatment processes is subject to question. The biological processes can be particularly hard to control. Tertiary treatment plants are complicated and will require much sophistication in operation. For adequate public health protection, fail-safe treatment processes and effluent monitoring devices must be developed. As long as it is necessary to construct treatment plants with by-passes, the reliability is inadequate for direct reuse.

The single treatment plant where water is introduced directly to the water supply is at Windhoek, South Africa. Windhoek, located in a water-short area, has been acquiring a portion of its water supply from renovated domestic sewage since 1968. Maturation ponds are used to hold the water for several days following tertiary treatment. Industrial wastes are collected in separate sewers and not treated with the domestic wastes. Hence, there is no danger of industrial effluents influencing the water quality.

The Windhoek experiment is a modified direct use application. The treated wastewater is returned to the head of the system, stored in ponds for thirty or more days, diluted with natural water, and used for only a portion of the year. It includes the safeguards of selected water input, of natural purification, dilution and storage time.

Direct reuse of reclaimed wastewater is not recommended as a means of supplementing public water supply because of the danger to consumers. At this point in time direct reuse represents an uncalled-for risk. Existing advanced waste treatment processes are not able to ensure complete removal of toxic organics or viruses.

Indirect Reuse

Cesspool discharges have caused the groundwater quality to deteriorate on many parts of Long Island. To protect the water quality, sewers are being constructed to carry wastewater to the shores of the island, from where it will be discharged to sea. As more and more of the water supply is carried to sea, the groundwater table will begin to decline. A lower water table will cause declining water levels in lakes and ponds, reduced streamflow, and less subsurface flow to sea, Although sewer construction will solve the problem of pollution, declining water levels will cause ecological, recreational, esthetic and water supply problems.

Recharge of renovated wastewater could help solve the above problems. Wastewater would be collected in sewers, transported to a central facility for treatment, and then recharged to the groundwater. The treatment would have to remove all constituents which might affect the health of the consumers or hinder recharge.

Four methods of recharge were investigated for use on Long Island. Each is briefly summarized below, with emphasis on the objective and the current feasibility on each type of recharge.

Basin Recharge

Recharge of renovated wastewater on Long Island through existing storm basins is feasible; however, the economics must be investigated. Basin recharge would primarily help maintain the esthetic and ecological aspects of Long Island's surface waters and brackish bays. There would also be an increase in water supply. The extent of this increase would depend on how much of the recharge water would permeate from the upper glacial aquifer to the Magothy and Jameco. The wastewater must be highly treated, although demineralization could be temporarily deferred. It is recommended that a project proposal using basin recharge be developed. The proposal will determine the economic feasibility of a basin recharge project.

Stream Bed Recharge

Flow augmentation through stream bed recharge is desirable primarily for esthetic and ecological reasons. There would be little benefit to the water supply except for some possible exfiltration through the bed. The recharged water would have to be highly treated to delay eutrophication. The technology to accomplish this type of recharge is currently available.

Spray Irrigation

Spray irrigation does not appear feasible for widespread use on Long Island. Extremely large land areas are required. A minimum of 65,000 acres (100 square miles) would be needed to treat 500 MGD. Land areas of this size are simply not available. There may be some limited possibilities for spray irrigation of small amounts of water on the eastern end of the island. The process may be applicable to use on sod farms. Beyond this, however, the prospect of spray irrigation solving the water supply problems of Long Island are non-existent.

Recharge into Injection Wells

Depending on the depth and location of a recharge well, any of the water needs of Long Island can be met. This ranges from shallow wells to raise the water table in one area to deep wells to prevent salt water intrusion along the coast.

In general, the problem of clogging is more of a deterrent to use of injection wells than any public health consideration. As evidenced at Bay Park, there are several reasons for well blockage, but the degree of blockage attributable to each reason is unknown.

Recharging treated wastewater through deep injection wells will not see widespread use until the mechanical problems have been resolved. It appears that some time will be required to solve these problems. Recharge through shallow wells may be feasible. Additional research is needed to determine this feasibility.

FEASIBILITY OF DESALINATION IN SOUTHEASTERN NEW YORK

INTRODUCTION

The oceans offer an inexhaustible source of water supply and the search for new sources has spurred investigations of means of desalting this water for potable uses. Additionally, desalting of inland brackish waters appears promising for communities with such resources (brackish waters are those unfit for human consumption due to large amounts of dissolved salts).

This report explores the several possible processes of desalting[1] which use physical, chemical, or electrical means of production. Each particular process is described and its utility and reliability is shown. The advantages and problems involved and any experience gained with actual plants is discussed. Based on these experiences and other studies, cost data estimates for desalting are developed. The cost estimates include capital and operating costs for different size plants and for operating these plants at various percentages of time, such as one year in five. The applicability of desalting in the southeastern New York region is discussed.

DESALTING PROCESSES

To explore the potentialities of saline water conversion, the U.S. Congress passed the Saline Water Act of 1952 (66 Stat. 328). It was enacted "To provide for research into and development of practical means for the economical production, from sea and other saline waters, of water suitable for agricultural, industrial municipal, and other beneficial consumptive uses, and for other purposes." The Secretary of the Interior established the Office of Saline Water to carry out the activities authorized by the act. It has concerned itself with the development of processes for the economic conversion of saline water into fresh water. It has coordinated and partially supported research and development on various aspects of

[1]The term desalting includes all dissolved salts, not just sodium chloride.

a number of processes proposed for saline water desalting. It has also provided for the construction, operation, and maintenance of five demonstration desalting plants to evaluate the technical feasibility of the more advanced processes. In addition, the Office of Saline Water serves as a clearinghouse for technical and economic information on desalting processes. As a result of this program, the development of desalting technology in the U.S. has been able to proceed with some order.

Conversion of saline water can be accomplished in many ways, several are in commercial use, some are being developed in pilot plants, and some are being examined in laboratories. Some methods operate by separating water from the saline solution, while others extract the salt from the solution. Only a few, however, have been seriously considered for major production plants.

DISTILLATION

Distillation is the oldest known method of desalting. The saltwater solution is boiled and the fresh water is vaporized while the dissolved particles remain in the solution. The vapor is then condensed to a product water which is suitable for consumption. This product water is relatively free of dissolved solids. There are many variations on the basic principle.

Currently the most popular process, particularly for the larger plants, is multistage flash distillation. A schematic of the process is shown in Appendix A. The seawater is heated and then introduced into a chamber in which the pressure is maintained sufficiently low to allow the solution to boil. Some of the water flahses into vapor, resulting in a lowering of temperature of the remaining concentrated solution (brine). The brine then flows into the next chamber where the pressure is further reduced and the process is repeated. The vaporized water is condensed and cooled by heat exchange with incoming seawater. A number of these flash stages are joined in series to remove a maximum amount of water from the solution. The multieffect-multistage process improves the multistage flash concept by recirculating the brine through a number of multistage units.

A recent improvement in saltwater distillation equipment is the use of the long-tube vertical evaporator. The salt water falls through a bundle of long tubes located inside a cylindrical chamber. It is heated by steam which surrounds the tubes. Some of the water from the salt solution vaporizes into steam which is used to heat the brine in the next chamber. While heating the salt water, the steam condenses into the fresh product water. A number of chambers are usually arranged in series to form a multieffect system. As in the flash process, the pressure is progressively reduced to allow the solution to boil at a lower temperature in each successive chamber. Experience in the operation of the long-tube vertical distillation process indicated that it can be used most advantageously when it is combined with a multistage flash feed preheater. The high efficiency of the long-tube vertical evaporator is a significant feature which may promote its increased use as larger desalting plants are developed.

A further development in distillation technology has been the use of vapor compression. The process generally employs one or more vertical tube evaporators. The steam produced is compressed and heated and then introduced into the evaporator chamber which surrounds the tubes; the steam condenses and transfers its heat to the solution, thereby promoting further boiling and producing more water. Recent proposals have recommended multistage flash distillation as a means of obtaining maximum process efficiency and water production. Illustrations showing both the long-tube vertical evaporator and the vapor compression modifications are in Appendix A.

Distillation methods have found extensive use in the chemical process industries, and their operation and design have been thoroughly investigated. Present research is devoted mainly to refining certain aspects of the processes for more efficient or optimum operation. Areas of continuing development include scale control methods, high-temperature operation, and equipment modifications for improved heat transfer, as well as the development of larger, more economical, process units.

ELECTRODIALYSIS

Electrodialysis is an electrically driven membrane process which makes use of an alternating parallel array of cation and anion selective membranes. When a direct electric current is passed through the system, the cations pass through cation-permeable membranes while the anions move in the opposite direction and pass through anion-permeable membranes. This results in salt depletion in the water passing between alternate membrane pairs, while water passing through the intervening pairs is enriched. Normally, only a portion of the dissolved salts are removed in a single pass through the system. Therefore, a number of units, or stages, are arranged in series to reduce the salinity to more acceptable levels.

This water may then be blended with other waters to further reduce the salinity level to the normal range of the water system. The necessary quantity of electric current, the required membrane area, and the cost of the process all depend on the amount of salt removed. Thus, electrodialysis is more economically advantageous for desalting brackish waters than sea water.

There are a number of limitations which have restricted extensive commercialization of the electrodialysis process. Organic materials in naturally occurring waters cause fouling of the membranes, eventually rendering them useless. Salt concentration polarization induces precipitation of pH-sensitive salts which scale the membranes. Electrodialysis stack components have high capital and maintenance costs. Costs of the electrodialysis process are increased by the necessity of feedwater pretreatment to eliminate organics and other harmful constituents, particularly from hard water. Further research is being conducted to develop membranes with higher selectivity, longer life, and lower cost. Operation at elevated temperatures is also being studied.

REVERSE OSMOSIS

Reverse osmosis is a process in which the normal osmotic flow across a semipermeable membrane has been reversed by applying a pressure to the saline water greater than its osmotic pressure. A schematic of the process is shown in Appendix A. There is a transfer of water through the membrane, in contrast to the transfer of ions in the electrodialysis process. As in the electrodialysis process, the salinity of the product water is usually reduced only to the acceptable level of 500 ppm. It can then be blended with natural waters before being introduced into the distribution system. The reverse osmosis process has some important advantages: the only energy consumed is that needed to pump the salt water up to its operating pressure; the process equipment is relatively simple; the process operates at ambient temperatures, minimizing scale and corrosion problems. Four promising designs, plate and frame, spiral wound, tubular and hollow fiber, have been developed and tested in pilot plant units. The process currently appears more applicable to the desalting of brackish waters than sea water.

The importance of the membrane in this process necessitates the development of low-cost membranes which combine high salt rejection, high water transmission at reasonable pressure, and long life. The problems of membrane fouling and concentration polarization must be overcome. Further activities in reverse osmosis development include investigations of operation with seawater, and of power recovery from the pressurized reject brine stream.

FREEZING

The freezing processes have an energy advantage resulting from the direct accomplishment of the heat transfer, i.e., there are no barriers to resist heat transfer. The process is illustrated in Appendix A. Basically, the salt water is cooled until ice is formed. The ice is then separated from the brine and melted to yield the product water. The freezing methods produce water that contains 300 to 500 ppm of dissolved solids. Another advantage of the freezing process derives from its operation at temperatures approaching the freezing temperature--scaling and corrosion are considerably lessened.

In the direct freezing method, the saline water is subjected to a low pressure, causing some of the water to vaporize. This in turn reduces the temperature of the brine below its freezing point and ice crystals form. The ice is then separated from the brine and melted.

The most successful freezing process appears to be the vacuum freeze-vapor compression process. Ice crystals are formed as in the direct freezing method. However, the water vapor evolved is compressed and subsequently discharges to the melting unit in which the vapor condenses and the ice melts simultaneously to compose the product water. Various equipment configurations have been proposed and tested, and further developments are intended to increase the capacity and reduce the power requirements of the freezer, melter, and compressor units.

OTHERS

A number of other possible processes for desalting have been considered. Some have been found to be technically unsound, while others, although technically feasible, are presently too costly to be developed for commercial desalting applications.

The hydrate process involves the use of compounds which accept water molecules in their lattice structure while rejecting the ionic constituents of saline water. A hydrating agent is mixed with the salt water and hydrate crystals are formed. The water and the hydrating agent separate into two immiscible liquids and are easily isolated. The process has been found to be technically achievable, but costly items of equipment give rise to inordinately high water costs.

Ion exchange methods have been proposed for desalting applications, but significant progress remains to be demonstrated in the water supply field. Serious problems, both qualitative and economic, have occurred in regeneration of exchangers.

Solvent extraction has also been suggested. However, a solvent with properties suitable for desalting process does not appear to be presently available at a reasonable cost.

Solar distillation in large stills can be readily accomplished in sunny climates. However, the process does not appear to be competitive with conventional distillation methods except in very small capacity ranges.

PROCESS DEMONSTRATIONS

As authorized by Congress (72 Stat. 1707), the Office of Saline Water has provided for the construction, operation, and maintenance of five demonstration conversion plants. These plants have permitted the testing of numerous process proposals and refinements. They have also illustrated the technical feasibility of the major processes mentioned above. The information derived from these demonstration plants has made some aspects of desalting processes commercially attractive and has promoted increased study and development.

EXISTING DESALTING PLANTS

The expanding technology of desalting has occasioned a tremendous increase in plant construction. As of January 1, 1970, there were 712 plants of greater than 25,000 gallons per day capacity in operation or under construction. These plants had a total capacity of 244,600,000 gallons per day, approximately half of which was being used to meet municipal water needs. The Middle East has the largest total desalting plant capacity in the world due to an abundance of cheap fuel and a lack of fresh water.

Approximately 95 per cent of the total capacity was being produced in plants employing some variation of the distillation process. There were 662 distillation plants producing 232 million gallons per day; 47 membrane plants (all but three using the electrodialysis process) producing 5.0 million gallons per day; and three freezing plants (all using the vacuum freeze-vapor compression process) producing 0.3 million gallons per day.

The largest plants operating were located at Terneuzen in the Netherlands and at Rosarita in Mexico. Both use the multistage flash distillation process. The Terneuzen plant is a combined water-power plant which operates on sea water. It has a capacity of 7.65 million gallons per day for industrial use. The Rosarita plant is a dual purpose plant, and it also converts sea water. It has a capacity of 7.50 million gallons per day which is provided for municipal use. In what appears to be a significant step forward, the U.S.S.R. is constructing a long-tube vertical distillation plant at Shevchenko with a planned ultimate capacity of 31.7 million gallons per day. Successful operation of such a facility should demonstrate the practicability of desalting applications on a larger scale.

The United States had 301 plants with a total capacity of 43.1 million gallons per day. The two largest ones use the multistage flash distillation process. The plant at Key West, Florida, has a capacity of 2.62 million gallons per day. A multistage flash module of 2.60 million gallons per day capacity is located at the Office of Saline Water's San Diego Test Facility.

BRINE DISPOSAL

The problem of plant effluent disposal has frequently been neglected in technological development, in plant design, and in its effects on product water costs. It is becoming apparent that future designs of desalting plants must consider the possibly harmful effects on natural features in the proximate area of the operation. Also, the costs of disposal of the brine (the concentrated salt water solution left after water has been extracted) have not usually been evaluated in determining desalting cost estimates, and they may constitute a sizable share of the total cost.

At coastal plants for seawater desalting, the distillation process is most likely to be employed. Increased temperature, salinity, and heavy metals concentration (particularly copper) are likely to seriously affect marine organisms, natural shore features, and local marine ecology. Studies by the Dow Chemical Company[6] indicate that discharged effluents will almost certainly have a detectable impact on the local marine environment. The most critical change is in the copper concentration which may be twenty times that encountered in the open ocean. Such a condition would be toxic to many marine organisms. It is expected that a proper intake-outfall system could be designed to minimize, or possibly eliminate, damage to adjacent marine life. This would, however, involve a relatively large expense.

When inland brackish waters are desalted, the brine disposal problem can be acute. Two proposals are presently being studied. Solar evaporation from large ponds is being evaluated; the effects of meteorological and chemical variables are being investigated. Deepwell injection is also being examined.

Perhaps the most beneficial alternative would be the development and commercial production of the mineral byproducts dissolved in sea water. Not only would it eliminate disposal problems, but overall plant costs could be reduced by sale of the minerals. It is already technically feasible to recover most of the dissolved minerals. However, for economic feasibility, these products must be competitive with those obtained from other sources, both in quality and in price.

DUAL PURPOSE PLANTS

Recently a number of studies have been conducted to consider the advantages of building large dual purpose electric power-water desalting plants. This type of plant is illustrated in Appendix A. Dual purpose plants provide reductions in the cost of energy supplied to the water plant, resulting in lower water production costs. For the distillation processes which are usually considered for large desalting plants, exhaust steam from the power plants is used to provide the process heat for the water plant. The power plant can be a nuclear or fossil-fueled facility.

Two of the more extensive studies of dual purpose plants are the Bolsa Island project[2] and the Parsons report on the New York City area[3]. The Bolsa Island plant was to be constructed on a man-made island off the coast of Southern California. Following intensive analysis, it was determined during 1968 that the project as originally conceived was clearly uneconomic to the electric utilities involved. Further progress was suspended, but investigation of possible alternatives is continuing to devise an arrangement satisfactory to all participating parties. From the desalting technology standpoint, the discontinuance of this project was unfortunate. It would have provided valuable information on the performance and operation of plants many times the size of those now operating.

The Parsons report also considered dual purpose plants in its cost analysis. They are included in the cost estimates section of this report.

The New York State Atomic and Space Development Authority has completed the preliminary design and engineering for a small multipurpose nuclear plant for power generation, water desalting, and radioactive isotope production on Long Island. Operation of such a plant would permit an economic evaluation of the multipurpose approach and also serve as a pilot desalting plant in the metropolitan New York area. It would provide basic information for subsequent design of the much larger facilities which would be needed to meet the area's future water supply requirements. However, the Authority has not yet decided to commit this research and demonstration project to construction and is exploring the environmental and economic benefits associated with other possibilities for producing pure water in conjunction with power plant operations, e.g., a combination power and wastewater renovation complex under a grant from the Water Quality Office of the Environmental Protection Agency.

An important consideration in the planning of dual purpose plants will be the choice of a site, particularly since the large-scale power plant which will be required for purposes of economics would most suitably be located outside of dense population centers and thus may increase the cost of water and power transport. In the determination of whether such facilities will be constructed there will, of course, have to be taken into account not only economics of construction and operation but other important public interests, such as protection and enhancement of the environment, conservation of scenic and natural resources and the provision of related community services.

COST ESTIMATES

Estimates developed in three reports were used to obtain an overview of costs at the current state of the art of desalting. For comparison they were updated to the Engineering News-Record Construction Cost Index value of 1400. To evaluate the various figures on a common basis, the following method was employed to determine the total capital and total annual costs:

TOTAL CAPITAL COSTS

1. construction costs
2. engineering and contingencies - 25% of 1.
3. land costs
4. legal and administrative costs - 10% of (1.+2.+3.)

TOTAL ANNUAL COSTS

1. amortization and interest - 5% for 40 years on the total capital costs
2. annual taxes - 2% of construction and land costs
3. personnel, chemicals, supplies and materials
4. power costs

STANFORD RESEARCH INSTITUTE [1]

Under contract with the Office of Saline Water, Stanford Research Institute updated a previous engineering cost study of water conversion processes. The report considered six processes believed to be the most economically favorable for application in the United States:

1. MSF - multistage flash distillation
2. VTE - vertical tube evaporation combined with multistage flash distillation
3. VC - vapor compression distillation combined with vertical tube evaporation and multistage flash distillation

4. VFVC - vacuum freeze-vapor compression
5. RO - reverse osmosis
6. ED - electrodialysis

These plants were assumed to be in operation 90 per cent of the time. The study did not include costs for water storage or conveyance. Neither were the costs of feed water intake or brine disposal considered. These elements can, however, constitute a significant portion of the total cost of desalting. Facilities for feedwater pretreatment were included in the cost estimates.

The costs estimates developed from the Stanford study are shown in Table 1.

RALPH M. PARSONS COMPANY [3]

The Ralph M. Parsons Company conducted an engineering study of desalting as related to the drought problems of northern New Jersey and New York City for the Northeast Desalting Team. The study was prompted by the drought of the 1960's. It was intended to explore, evaluate, and determine the economics of desalting plants in providing drought proofing for the northern New Jersy and New York City water supply systems. Only the multistage flash distillation, electrodialysis, and reverse osmosis processes were considered. Capacities of 100, 150, and 300 million gallons per day (MGD) were investigated. The plants were assumed to operate 85 per cent of the time at full capacity. Partial operation at 1, 30, and 50 per cent of the time over the life of the plant was also evaluated; for the distillation plants, an island and a mainland site were hypothesized, while the membrane plants were considered to be located at Indian Point, New York, on the Hudson River.

The distillation plants, either single or dual purpose, were adjacent to power plants using either nuclear or fossil fuel. They were to be constructed in 50 MGD modules of the single-effect multistage flash process. Low-pressure turbines were employed to effectively use the power plant exhaust steam when the water plant was not operating. Water conveyance costs were included.

The electrodialysis plants were to consist of either four or five stages with design salinities of 5300 or 9100 parts per million (ppm) of dissolved solids, respectively. The reverse osmosis plants would be designed for a salinity of 9,000 ppm. Both pretreatment and conveyance costs were included for these membrane plants. They would be shut down whenever the salinity of the river water exceeded the design salinity.

Tables 2-6 show the cost estimates derived from the Parsons report. Tables 2-4 indicate the costs of the various plants at full operation (85 per cent plant operation), while costs of partial operations are illustrated in Tables 5-6. The large number of plant sizes and process variations studied by the Parsons Company enabled curves to be plotted. Figures 1 and 2 show the effect of plant capacity for 85 per cent operation on water plant total capital costs and on water costs per million gallons. Figures 3, 4, and 5 show the effect of partial operations on water costs for the 100, 150, and 300 MGD plants.

STONE AND WEBSTER ENGINEERING CORPORATION [5]

Stone and Webster conducted an optimization study of electrodialysis on esturial waters for the New York State Conservation Department. A number of plant configurations were studied, but the one most applicable here was a 100 MGD plant which would be located on the Hudson River at Indian Point, New York. This plant had a two-stage arrangement and would process river water with salinities up to 6,500 ppm. Costs include feedwater pretreatment and product water conveyance.

The cost estimates developed from the Stone and Webster figures are shown in Table 7.

RESULTS

Table 1 compares costs of the major desalinization processes for relatively small capacity plants. These figures provide some readily apparent conclusions. Power cost is the most important cost item for the multistage flash distillation and vertical tube evaporation processes. This results from the large steam requirements for heating and boiling the saline water solution. For the vapor compression distillation and vacuum freeze-vapor compression processes, equipment amortization is the most significant cost constituent due to high compressor costs. Personnel and supplies costs are most important for the reverse osmosis and electrodialysis plants. They consist mainly of membrane replacement costs and labor costs.

The water cost figures in Table 1 are quite high compared to the estimates commonly made for conventional sources. However, the value of $274/MG for the 10 MGD electrodialysis plant does appear promising. It should be noted though that this plant would only be able to process water with salinities below 2500 ppm. If the electrodialysis plant were located, as in the Parsons study, at Indian Point on the Hudson River, it would be shut down much of the time during drought periods when its operation would be needed most.

It should also be emphasized that the costs of conveying the water to the distribution system have not been considered in computing the figures of Table 1.

Hence, the apparent attractiveness of some of these figures may be very misleading.

Tables 2-4 (from the Parsons Report) show the costs of large desalting plants. Their significance is illustrated in Figures 1 and 2. Figure 1 shows the effect of plant size on total capital costs, while Figure 2 shows the effect of plant size on water costs. (Only the island site values were plotted for the distillation plants). There is an appreciable scale effect, particularly for the membrane plants and the single purpose nuclear-fueled plant. Figure 2 demonstrates that the water costs are considerably lessened for these plants as the plant capacity is increased. This results primarily from use of common facilities in the larger plants.

These figures were derived from values in the Parsons report, That study considered a mainland and an island site for its distillation plants. The mainland site had significantly higher costs because the study provided for conveyance to northern New Jersey as well as to the New York City system. If this were eliminated, the costs for the mainland site would probably be slightly less than those for the island site.

The best water cost was found to be $449/MG for the 300 MGD dual purpose, nuclear-fueled distillation plant at the island site (see Table 2). This was less than the smaller multistage flash distillation plants of Table 1, even though the figures in Table 2 included product water conveyance costs. This example clearly illustrates the economic advantages which should occur when current plants are scaled up to larger capacities. The advantages of dual purpose operation are demonstrated when compared to their single purpose counterparts. The 300 MGD single purpose, nuclear-fueled distillation plant at the island site was determined to produce water at a cost of $501/MG. This is $52/MG more than the cost of water from the corresponding dual purpose plant above. Water costs for the large membrane plants (see Tables 3 and 4) can be seen to be much higher than the smaller plants of Table 1. Here, water conveyance costs had quite an effect. (It was assumed that the water would be delivered to Kensico Reservoir, a distance of some 14 miles.) The Parsons report shows that water conveyance facilities contribute nearly 40 per cent of the total equipment costs of the membrane plants, while the figures of Table 1 do not account for water conveyance at all.

The effect on water costs of operating only part of the time is illustrated in Figures 3, 4 and 5. The actual values are listed in Table 6. Data were not available to continue these curves below the 30 per cent operation point. This area should, however, be investigated. It appears that the costs per MGD of water at the lower range of operation may be less than the costs of maintaining large additional supplies of water which would seldom be used. For this type of operation, desalination may already be economically practical.

Implicit in this analysis is the assumption that the distillation and membrane plants will perform equally well. It should be recognized, however, that this study of large plants necessitated a greater degree of extrapolation of available data for the membrane plants than for the distillation plants. In addition, product water from the membrane plants will require blending since it will still have a higher salinity than that of the natural waters in the distribution system. Product water from the distillation plants will have a lower salinity than the natural waters.

Table 7 shows the cost values derived from the Stone and Webster report. The figures are significantly lower than those of the corresponding plant in the Parsons report (see Table 3). The most significant difference is in the construction cost figures. This resulted from the difference in approach. The Stone and Webster plant was designed with only two electrodialysis stages, while the Parsons report considered plants of four and five stages. Therefore, the Stone and Webster plant would not be able to operate on waters of as high salinity as would the Parsons plants.

It should be possible to reduce desalting costs by further process developments, including design modifications, new equipment configurations, improved construction materials, and better operating procedures. In the distillation processes, lower costs might result from reductions in steam costs by employing dual purpose plants. Development of improvements in membranes will yield lower costs for electrodialysis and reverse osmosis plants. Operating labor provides a significant cost item in all desalinization processes. This may lead to automation of process control, particularly as experience is gained in the operation of larger plants.

Figure 6 was furnished to the Southeast Water Supply Commission by the Office of Saline Water. It illustrates the anticipated cost and development of desalting plants. As shown, plants in the size range of 1000 MGD will not be available before the year 2000. Water costs are expected to vary between $220 and $350 per million gallons at that time, based on 1971 dollars.

DISCUSSION

It appears that southeastern New York will require additional water sources in the near future. Yet, water production in the area may be required only during drought periods. Thus, a large desalting plant could be shut down for extended periods and operated only when necessary. It would have the advantage of being able to operate independent of the uncertainties of rainfall and runoff. Conventional sources, however, would probably be severely affected by a prolonged drought. On the other hand, as the area grows in population, the plant could be operated to supply a fixed, continuous quantity of potable water to be added to the natural supply.

To significantly increase the area water supply by desalting processes, it will be necessary to employ large plants. This presents two important problems. First, although it is technologically possible to build these facilities, there has not as yet been any application on such a large scale. Neither has there been sufficient consideration of the problems that may be involved in operating large plants. Secondly, to be economically attractive, desalting must become competitive with other possible sources of water for the region. As the figures above illustrate, this is not yet the case. However, further investigations of plants designed to operate for limited periods of time are warranted.

As seen from Figure 6, it will be the year 2000 before plants in the 1000 MGD range will be developed. Even at this large capacity, costs are high ranging from \$220 per MG to \$350 per MG. Competitive desalting plants of the size needed in southeastern New York certainly will <u>not</u> be available before that time.

With these costs, a report from the National Water Commission issued May, 1972, concluded that desalting will have a rather narrow market in municipal water supply. The most immediate possibility is for small plants of less than 10 MGD capacity in areas with limited fresh water and the availability seawater or brackish water. There is some opportunity for desalting with plants of 50 MGD or higher to give supplemented or incremental municipal water supply. These opportunities will require further research. Large dual-purpose plants in the 50 to 250 MGD range could serve the needs of large cities in arid areas near the coast. The technology involved would be a major extrapolation from the present state of the art and will require extensive research and development programs. The report concludes that the major research needs are for plants of 50 MGD and larger.

This was also concluded by a joint study of <u>Dual-Purpose Nuclear Power and Desalting Plants for the New York Metropolitan Region</u>, issued June, 1972. This study stated that actual prototype experience with a 50 MGD or larger plant should be acquired before further desalting plans are considered for the New York area. However, the study did feel that desalting from dual-purpose plants in conjunction with existing water supply facilities had sufficient premose for the area and recommended that a prototype plant in the 25 to 50 MGD range be initiated in the area by 1985.

FINDINGS AND CONCLUSIONS

1. It is technically possible to supplement public water supply by desalting, although this is presently done only on a small scale.

2. There are several processes available for desalting. Distillation, electrodialysis, and freezing have been demonstrated in actual plant operations. The greatest amount of experience has been gained with distillation.

3. Reverse osmosis appears to be a promising process for the future, but may require more research and development.

4. Disposal of the heated brine effluent from desalting plants is a serious environmental problem. Acceptable brine disposal will add costs to desalting.

5. Dual purpose plants which include electrical power generating as well as desalting currently offer the least expensive way of desalination and minimize the brine disposal problem.

6. It is estimated that a 300 MGD dual purpose, nuclear-fueled distillation plant operating at full capacity could supply water at about $450 per million gallons including capital and operating costs. A 300 MGD, single purpose, nuclear-fueled distillation plant could supply water at about $500 per million gallons. These costs include treated water transmission costs. Brine disposal costs, which will substantially increase the cost of desalting are not included. Furthermore, costs per MGD shoot up very quickly if desalination is only used part of the time to supplement existing sources during times of drought.

7. All of the actual experience with desalting has been gained from rather small plants. The largest plant existing today only has a capacity of 7.6 MGD. Extrapolation of economics, reliability, and experience from such small plants to the much larger capacities of practical sizes does not provide adequate information of the state of the art. If a large demonstration plant of 50 MGD capacity were built, it would remove much of the guesswork associated with these extrapolations.

RECOMMENDATIONS

1. Desalting is not recommended at this time as a supplementary water supply source for southeastern New York because:

a. The cost is very high when compared to more conventional sources. It has been estimated that desalting will cost about $450 per million gallons excluding brine disposal costs for a 300 MGD dual purpose nuclear distillation plant. A more conventional source would cost about $200 per million gallons to construct and operate, or about 1/3 as much as total desalination costs.

b. The effect on the environment of large quantities of waste brine is not precisely known. More research is needed on the brine disposal problem and its environmental and economic effects.

c. The lack of actual engineering, operation and cost data for large scale desalting plants.

2. It does not appear that desalting will become feasible for the use in Southeastern New York for many years. Other sources are recommended to meet the more immediate water supply needs of the area.

3. To avoid the present uncertainties, to expand on the present knowledge, and to gain engineering and operating data, a large scale desalting plant should be constructed. This plant, preferably dual purpose and of at least 50 MGD capacity, should be constructed by the federal government because of the national interest and implications.

TABLE 1 Comparative Costs* of Desalting Processes[1] (million dollars) ENR = 1400

Process	MSF	MSF	VTE	VTE	VC	VFVC	VFVC	RO	RO	ED	ED
Capacity (MGD)	10	50	10	50	8	1	5	1	10	1	10
1. Construction	8.11	32.93	6.27	22.90	7.04	1.43	6.26	.709	4.37	.587	3.80
2. Engineering & Contingencies	2.03	8.24	1.57	5.73	1.76	.36	1.57	.177	1.09	.147	.95
3. Land	.25	1.00	.25	1.00	.20	.05	.15	.010	.06	.010	.06
4. Legal & Administrative	1.04	4.22	.81	2.96	.90	.18	.80	.090	.55	.074	.48
TOTAL CAPITAL COST	11.43	46.39	8.90	32.59	9.90	2.02	8.78	.986	6.07	.818	5.29
1. Amortization & Interest	.57	2.32	.45	1.63	.50	.101	.44	.049	.30	.041	.264
2. Annual Taxes	.17	.68	.13	.48	.14	.030	.13	.014	.09	.012	.077
3. Personnel, etc.	.40	1.25	.39	1.09	.42	.115	.39	.118	.75	.070	.379
4. Power	.78	3.47	.69	3.47	.27	.052	.26	.016	.16	.018	.183
TOTAL ANNUAL COST	1.92	7.72	1.66	6.67	1.33	.298	1.22	.197	1.30	.141	.903
WATER COST ($/MG)	584	471	504	405	507	907	742	600	395	430	274

* Does not include treated water transmission costs or brine disposal costs.
** For legend of Processes, see Page

TABLE 2 Costs* of Large Distillation Plants[3] (million dollars) ENR = 1400

A. Dual Purpose Plants

1. Nuclear-fueled

Location	Island Site			Mainland Site		
Capacity (MGD)	100	150	300	100	150	300
1. Construction	135.0	188.2	347.3	159.0	212.4	371.1
2. Engineering & Contingencies	33.7	47.1	86.8	39.7	53.1	92.7
3. Land	1.6	1.8	2.2	1.6	1.8	2.2
4. Legal & Administrative	17.0	23.7	43.6	20.0	26.7	46.6
TOTAL CAPITAL COST	187.3	260.8	479.9	220.3	294.0	512.6
1. Amortization & Interest	9.36	13.03	23.97	11.02	14.69	25.62
2. Annual Taxes	2.73	3.80	6.99	3.21	4.28	7.47
3. Personnel, etc.	2.39	3.30	6.02	2.44	3.33	6.04
4. Power	1.59	2.43	4.85	1.59	2.44	4.86
TOTAL ANNUAL COST	16.07	22.56	41.83	18.26	24.74	43.99
WATER COST ($/MG)	518	485	449	589	532	474

* Includes finished water conveyance costs, but does not include brine disposal.

TABLE 2 (continued)

2. Fossil-fueled

Location	Island Site			Mainland Site		
Capacity (MGD)	100	150	300	100	150	300
1. Construction	133.3	186.3	343.3	157.1	210.3	367.0
2. Engineering & Contingencies	33.3	46.6	85.8	39.3	52.6	91.7
3. Land	1.6	1.8	2.2	1.6	1.8	2.2
4. Legal & Administrative	16.8	23.5	43.1	19.8	26.5	46.1
TOTAL CAPITAL COST	185.0	258.2	474.4	217.8	291.2	507.0
1. Amortization & Interest	9.25	12.90	23.69	10.87	14.55	25.36
2. Annual Taxes	2.70	3.76	6.91	3.17	4.24	7.38
3. Personnel, etc.	2.34	3.22	5.87	2.39	3.36	5.91
4. Power	3.57	5.34	10.60	3.57	5.35	10.61
TOTAL ANNUAL COST	17.86	25.22	47.07	20.00	27.50	49.26
WATER COST ($/MG)	575	542	507	644	592	529

TABLE 2 (continued)

B. Single Purpose Plants

1. Nuclear-fueled

Location	Island Site			Mainland Site		
Capacity (MGD)	100	150	300	100	150	300
1. Construction	154.6	207.3	365.7	178.2	231.2	389.6
2. Engineering & Contingencies	38.6	51.8	91.4	44.6	57.7	97.4
3. Land	1.4	1.5	1.9	1.4	1.5	1.9
4. Legal & Administrative	19.5	26.1	45.9	22.4	29.0	48.9
TOTAL CAPITAL COST	214.1	286.7	504.9	246.6	319.4	537.8
1. Amortization & Interest	10.70	14.33	25.20	12.32	15.96	26.85
2. Annual Taxes	3.12	4.18	7.35	3.59	4.65	7.83
3. Personnel, etc.	3.19	4.11	6.97	3.23	4.14	6.99
4. Power	2.39	3.59	7.19	2.39	3.60	7.20
TOTAL ANNUAL COST	19.40	26.21	46.71	21.53	28.35	48.87
WATER COST ($/MG)	625	564	501	693	608	526

TABLE 2

2. Fossil-fueled

Location	Island Site			Mainland Site		
Capacity (MGD)	100	150	300	100	150	300
1. Construction	128.0	178.0	327.4	152.0	202.0	351.3
2. Engineering & Contingencies	32.0	44.5	81.8	38.0	50.5	87.8
3. Land	1.4	1.5	1.9	1.4	1.5	1.9
4. Legal & Administrative	16.1	22.4	41.1	19.1	25.4	44.1
TOTAL CAPITAL COST	177.5	246.4	452.2	210.5	279.4	485.1
1. Amortization	8.87	12.32	22.60	10.52	13.95	24.24
2. Annual Taxes	2.59	3.59	6.59	3.07	4.07	7.06
3. Personnel, etc.	2.73	3.63	6.37	2.78	3.67	6.39
4. Power	6.84	10.20	20.41	6.84	10.21	20.42
TOTAL ANNUAL COST	21.03	29.74	55.97	23.21	31.90	58.11
WATER COST ($/MG)	677	638	600	748	685	625

TABLE 3 Costs* of Large Electrodialysis Plants[3] (million dollars) ENR = 1400

Number of Stages	5	5	5	4	4	4
Capacity (MGD)	100	150	300	100	150	300
1. Construction	156.7	193.1	299.0	144.4	174.8	264.1
2. Engineering & Contingencies	39.2	48.2	74.7	36.1	43.6	66.0
3. Land	.05	.07	.14	.04	.06	.12
4. Legal & Administrative	19.6	24.1	37.4	18.1	21.9	33.0
TOTAL CAPITAL COST	215.5	265.5	411.2	198.6	240.4	363.2
1. Amortization & Interest	10.76	13.27	20.58	9.92	12.01	18.15
2. Annual Taxes	3.13	3.86	5.98	2.89	3.50	5.28
3. Personnel, etc.	6.51	9.50	18.26	5.52	7.98	15.23
4. Power	1.91	2.85	5.71	2.06	3.08	6.18
TOTAL ANNUAL COST	22.31	29.48	50.53	20.39	26.57	44.84
WATER COST ($/MG)	718	633	542	658	570	482

* Includes finished water conveyance costs, but does not include brine disposal.

TABLE 4 Costs* of Reverse Osmosis Plants[3] (million dollars) ENR = 1400

Capacity (MGD)	100	150	300
1. Construction	164.3	193.2	274.8
2. Engineering & Contingencies	41.1	48.3	68.7
3. Land	.03	.04	.08
4. Legal & Administrative	20.5	24.5	34.4
TOTAL CAPITAL COST	225.9	265.7	378.0
1. Amortization & Interest	11.28	13.28	18.90
2. Annual Taxes	3.29	3.86	5.50
3. Personnel, etc.	11.53	16.78	32.66
4. Power	2.44	3.38	6.78
TOTAL ANNUAL COST	28.54	37.30	63.84
WATER COST ($/MG)	921	803	685

* Includes finished water conveyance costs, but does not include brine disposal.

TABLE 5 Total Annual Costs of Partial Operations[3] (million dollars) ENR = 1400

	Capacity MGD	% of Time Operating 0	30	50	85
A. Distillation					
1. Dual purpose plants					
a. Nuclear-fueled	100	13.29	14.59	15.39	16.49
	150	18.43	20.43	21.53	23.13
	300	33.61	37.51	39.76	43.01
b. Fossil-fueled	100	13.30	15.15	16.35	18.15
	150	18.41	21.26	22.96	25.61
	300	33.55	39.20	42.60	47.85
2. Single purpose plants					
a. Nuclear-fueled	100	14.77	16.92	18.27	20.07
	150	19.66	22.71	24.51	27.01
	300	34.20	39.95	43.20	48.15
b. Fossil-fueled	100	11.91	15.46	17.91	21.36
	150	16.56	21.71	24.96	30.11
	300	30.04	40.29	46.54	56.84
B. Electrodialysis					
1. 5-stage	100	15.06	17.83	19.67	22.87
	150	18.84	22.91	25.60	30.32
	300	29.87	37.57	43.02	52.20
2. 4-stage	100	13.87	16.21	17.74	20.41
	150	17.05	20.44	22.67	26.62
	300	25.19	32.62	37.24	44.93
C. Reverse Osmosis	100	15.12	20.32	23.52	28.82
	150	17.69	25.39	30.19	37.99
	300	25.10	40.25	49.70	65.25

TABLE 6 Water Costs for Partial Operations* (dollars per million gallons) ENR = 1400

	Capacity MGD	% of Time Operating 0	30	50	85
A. Distillation					
1. Dual purpose plants					
a. Nuclear-fueled	100	---	1331	844	532
	150	---	1244	786	496
	300	---	1142	726	463
b. Fossil-fueled	100	---	1384	896	586
	150	---	1293	838	551
	300	---	1195	778	515
2. Single purpose plants					
a. Nuclear-fueled	100	---	1545	1005	647
	150	---	1384	896	581
	300	---	1216	789	518
b. Fossil-fueled	100	---	1411	981	688
	150	---	1321	912	647
	300	---	1227	849	611
B. Electrodialysis					
1. 5-stage	100	---	1627	1077	737
	150	---	1395	934	652
	300	---	1142	786	562
2. 4-stage	100	---	1479	973	658
	150	---	1244	827	573
	300	---	992	679	482
C. Reverse Osmosis	100	---	1855	1288	929
	150	---	1545	1104	816
	300	---	1225	907	701

TABLE 7 Costs* of Large Electrodialysis Plant[5] (million dollars) ENR = 1400

Number of Stages	2
Capacity (MGD)	100.
1. Construction	47.6
2. Engineering & Contingencies	11.8
3. Land	1.5
4. Legal & Administrative	6.1
TOTAL CAPITAL COST	67.2
1. Amortization & Interest	3.36
2. Annual Taxes	.98
3. Personnel, etc.	3.67
4. Power	3.58
TOTAL ANNUAL COST	11.59
WATER COST ($/MG)	318

* Includes conveyance costs, but does not include brine disposal.

FIGURE I
TOTAL CAPITAL COST VS PLANT CAPACITY

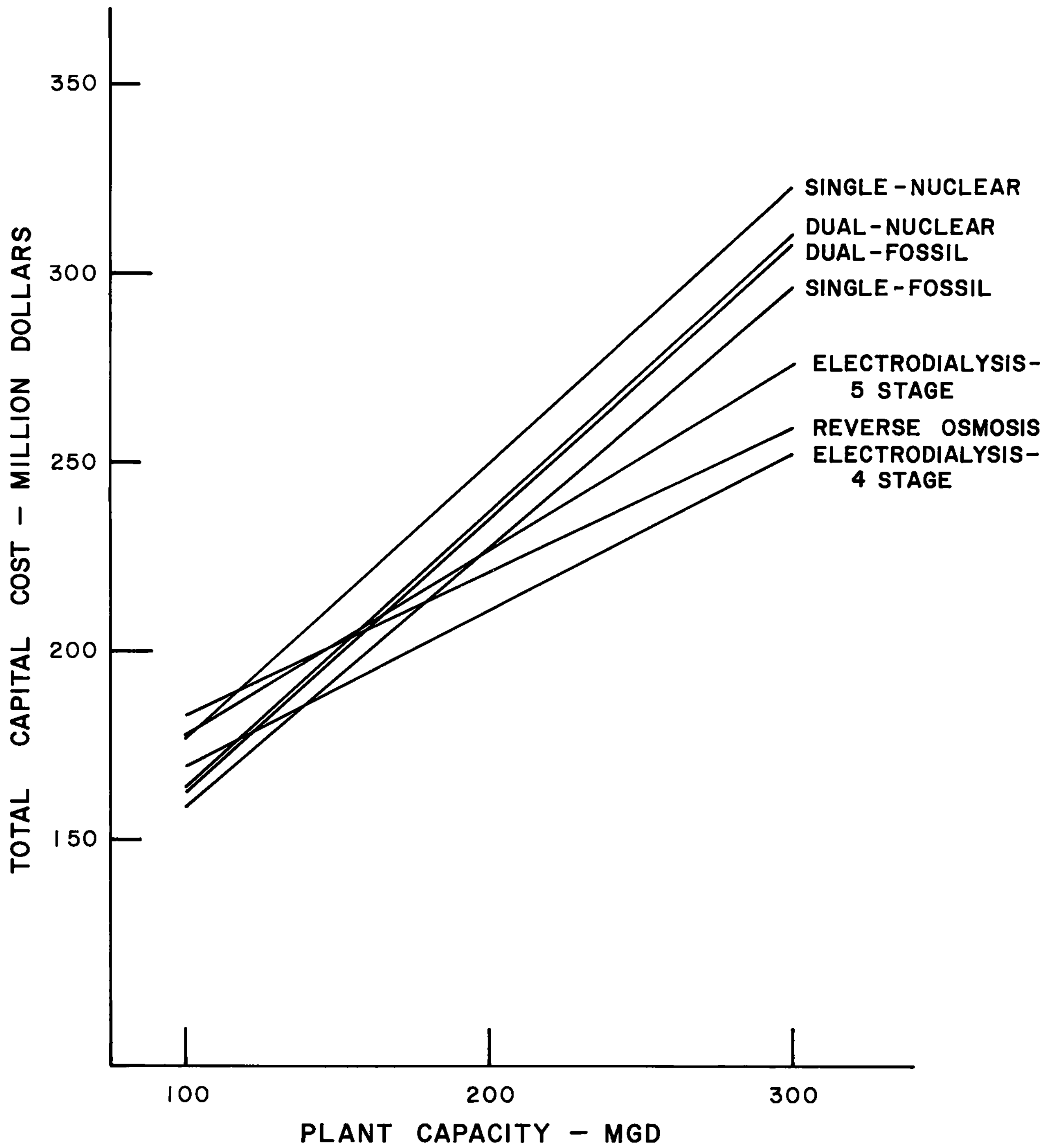


FIGURE 2

WATER COST VS PLANT CAPACITY

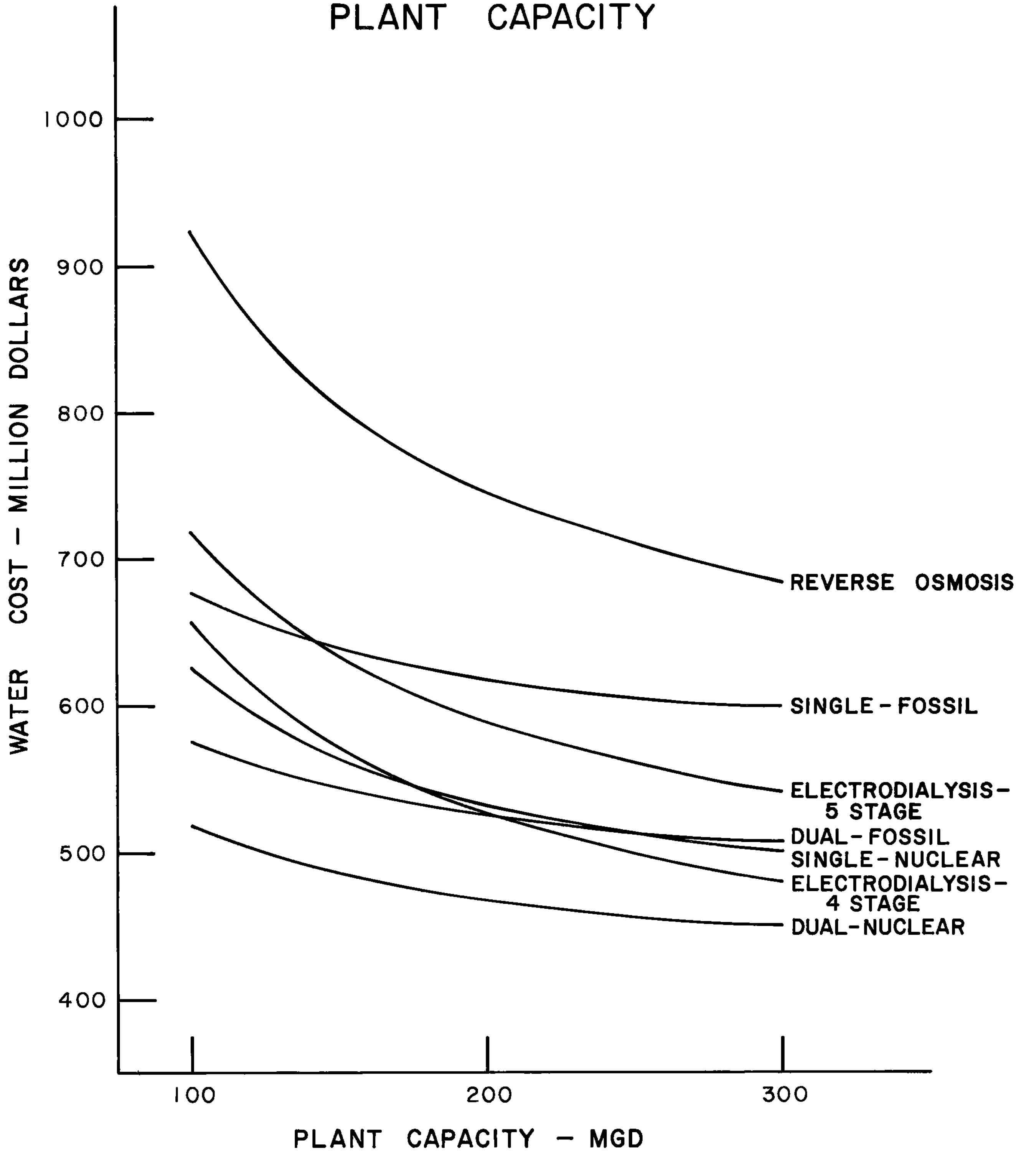


FIGURE 3

WATER COST

VS

% OPERATION FOR 100 MGD PLANTS

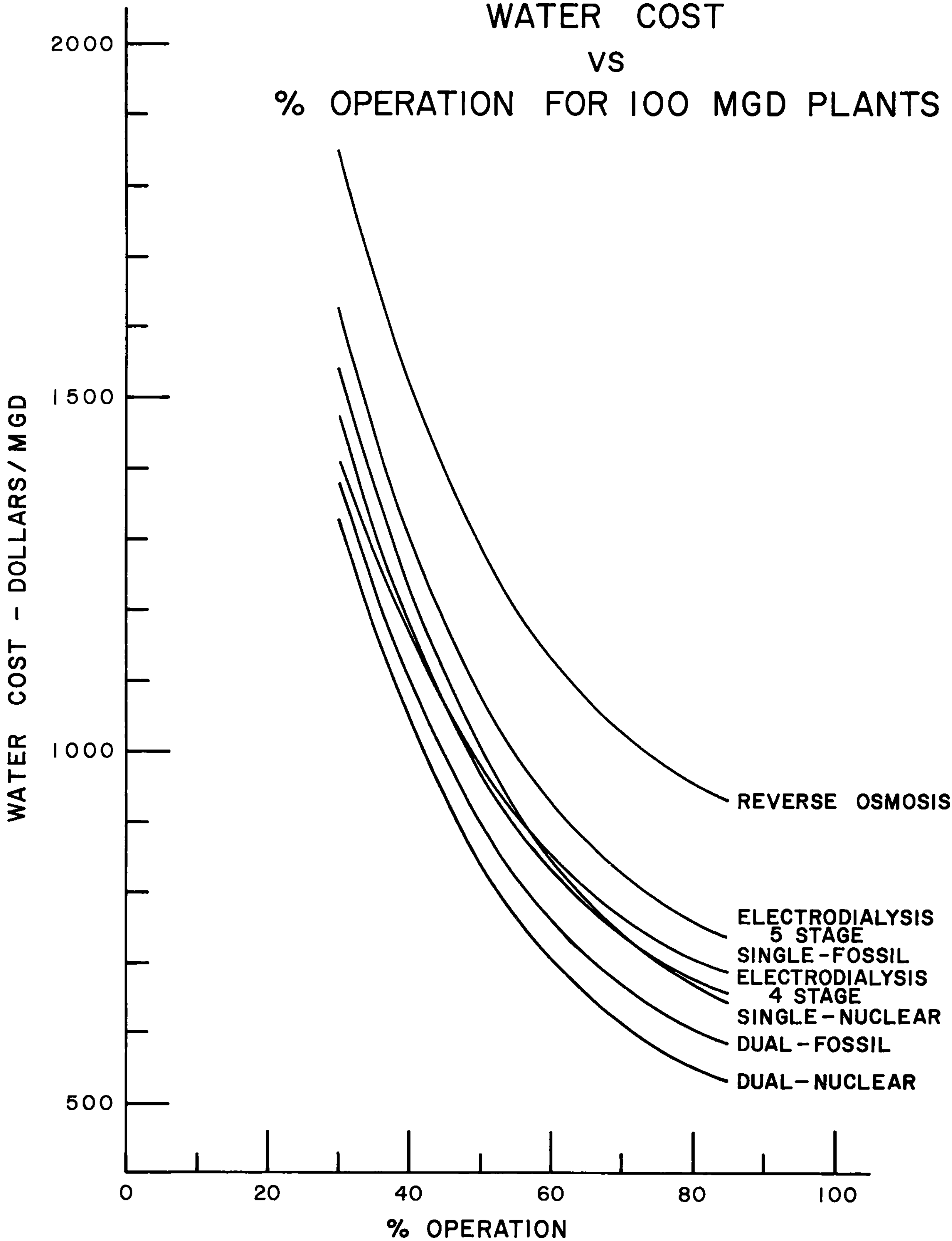


FIGURE 4
WATER COST
VS
% OPERATION FOR 150 MGD PLANTS

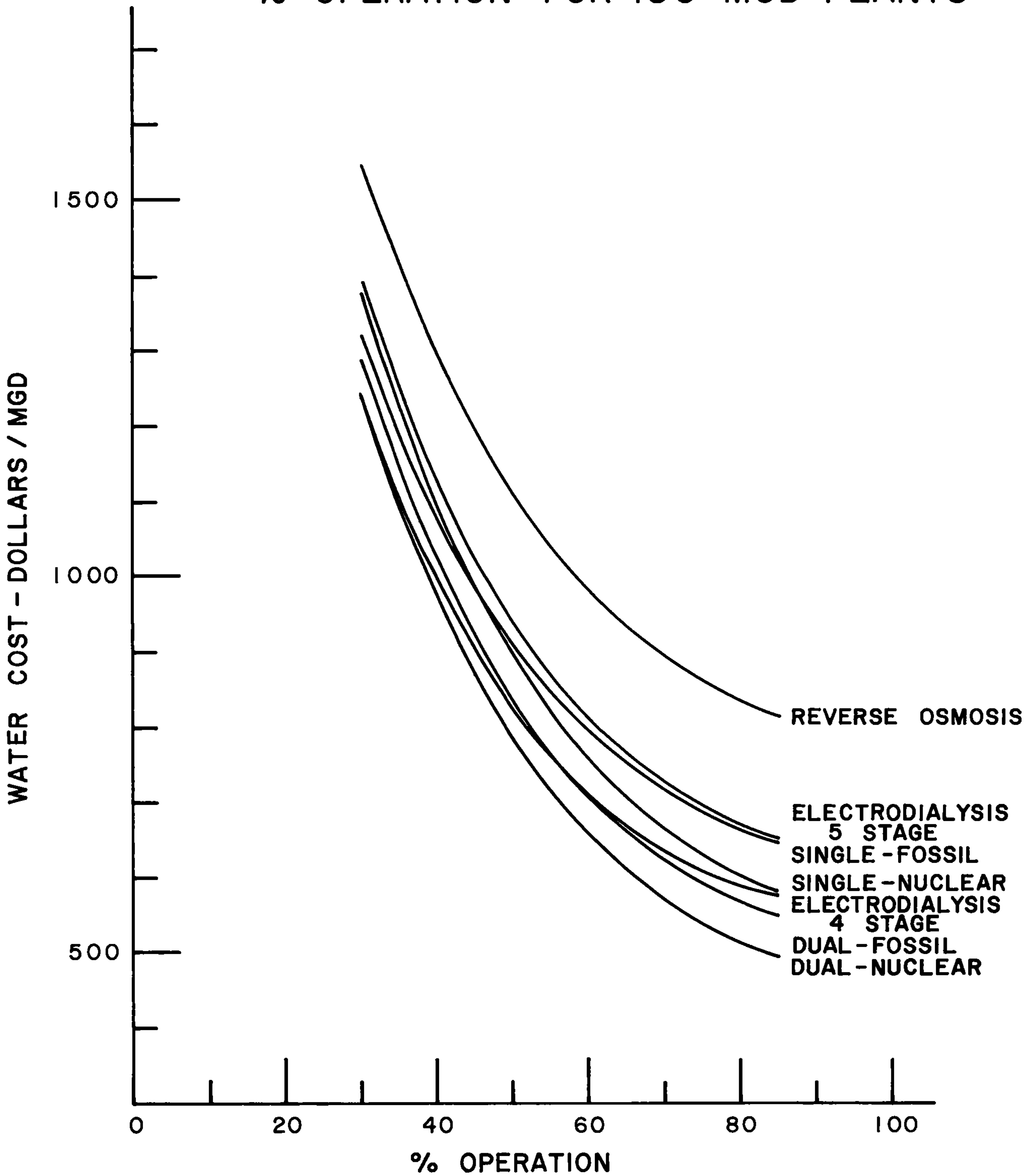


FIGURE 5

WATER COST VS % OPERATION FOR 300 MGD PLANTS

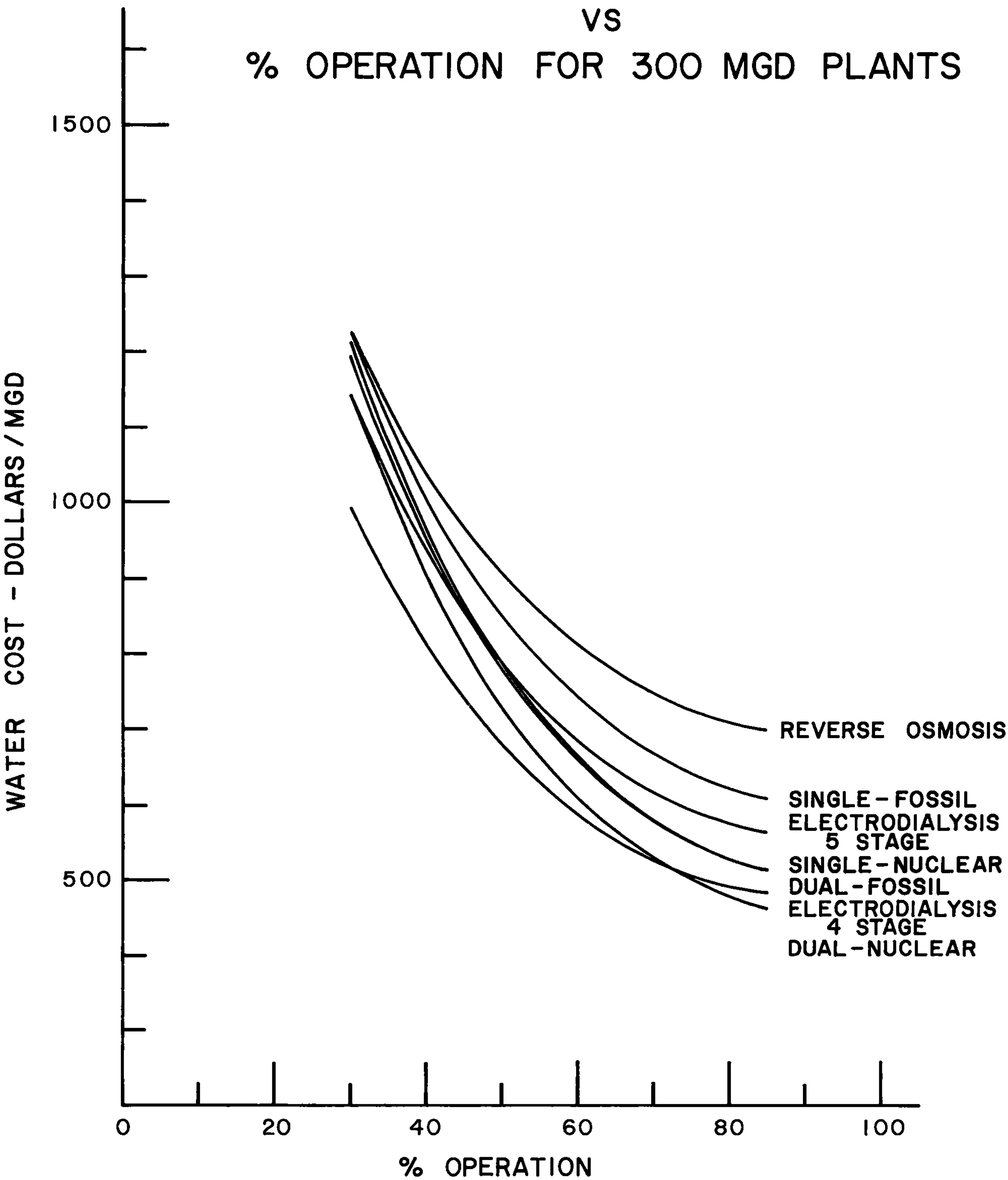
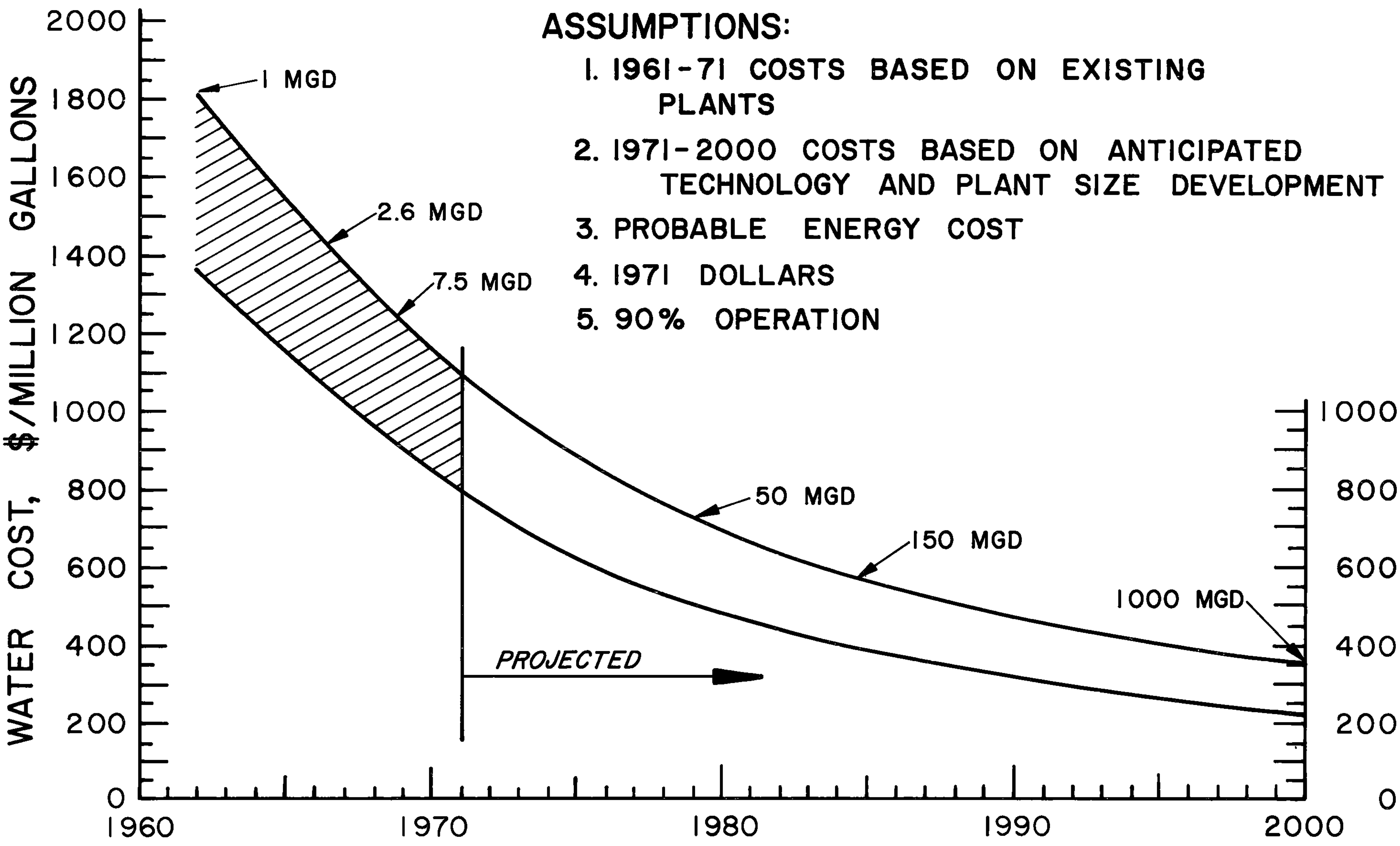


FIGURE 6

SEAWATER DESALTING COST



FROM OFFICE OF SALINE WATER

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FEASIBILITY OF WEATHER MODIFICATION TO AUGMENT WATER SUPPLY

INTRODUCTION

This report investigates the feasibility of supplementing water supply in southeastern New York by weather modification. Weather modification refers to techniques which can be used to increase rainfall, suppress lightning, dissipate fog, modify tornadoes and hurricanes, or decrease hail. Weather modification to increase rainfall is done by dispersing certain materials, such as dry ice or silver iodide in clouds. This technique, called cloud seeding, has been moderately successful when employed under appropriate conditions.

During an average year, only about 10 per cent of the total atmospheric moisture passing over the United States will fall as precipitation. Many persons view the remaining 90 per cent as a valuable untapped resource. To them weather modification is an attractive possibility for acquiring additional water. They feel the process requires practically no capital expenditures since existing reservoirs and aqueducts can be used to collect and distribute the added precipitation. This eliminates the need for new dams and aqueducts. Since cloud seeding would not be needed in wet years, there would be no operating or maintenance costs during average years. Theoretically, in dryer years, the clouds could be seeded to any extent desirable producing the required yields.

Although these arguments can be very appealing, they do not accurately reflect the current state of the art of weather modification. Precipitation modification must first satisfy the requirement of being able to <u>reliably</u> produce significant increases in precipitation before it can be accepted as a means of supplementing water supplies. The major objective of this report is to determine if precipitation modification can fulfill this requirement of reliability in southeastern New York. Cloud physics and the mechanisms of precipitation and cloud seeding will be briefly discussed to understand weather modification and whether it will or will not work. Although the terms cloud seeding, weather modification, and precipitation modification have slightly different meanings, they will be used interchangeably in this report and will refer exclusively to attempts to artificially increase precipitation.

MECHANISMS OF PRECIPITATION FORMATION*

To appreciate the applicability of weather modification to the water supply problems of southeastern New York, it is useful to review the processes of precipitation formation. Precipitation formation occurs in two steps; first in cloud formation and second in raindrop or snowflake formation. These steps are shown schematically in Figure 7.

CLOUD FORMATION

Clouds are actually millions of tiny water droplets or ice crystals. Three ingredients, water vapor, rising air masses, and condensation nuclei, are necessary for the formation of clouds. Water vapor (evaporated or gaseous water) is always present in the atmosphere. Air masses which are rising undergo expansion and cooling. Cooler air cannot carry as much water vapor as warmer air. Consequently, as air rises and cools water vapor begins to condense. Condensation is the process whereby water molecules in the gaseous phase are transformed into liquid water droplets. Water molecules will only condense on tiny microscopic solid particles called condensation nuclei. The atmosphere contains enormous quantities of consensation nuclei, numbering from 10 to 1000 per cubic centimeter. The most active nuclei are particles of salt from the sea, although soil, dust and smoke also serve as nuclei.

Stated in other words, water vapor, a lifting process, and condensation nuclei contribute to the formation of a cloud droplet.** As an air mass rises,

---

* The information in this section is taken from references 2, 4, 8 and 9.

** The diameter of an average cloud droplet is about 105 millimeter (or about .002 of an inch). An ordinary raindrop averages about 3mm in diameter, a fine rain or drizzle about 0.2 to 0.5 mm.

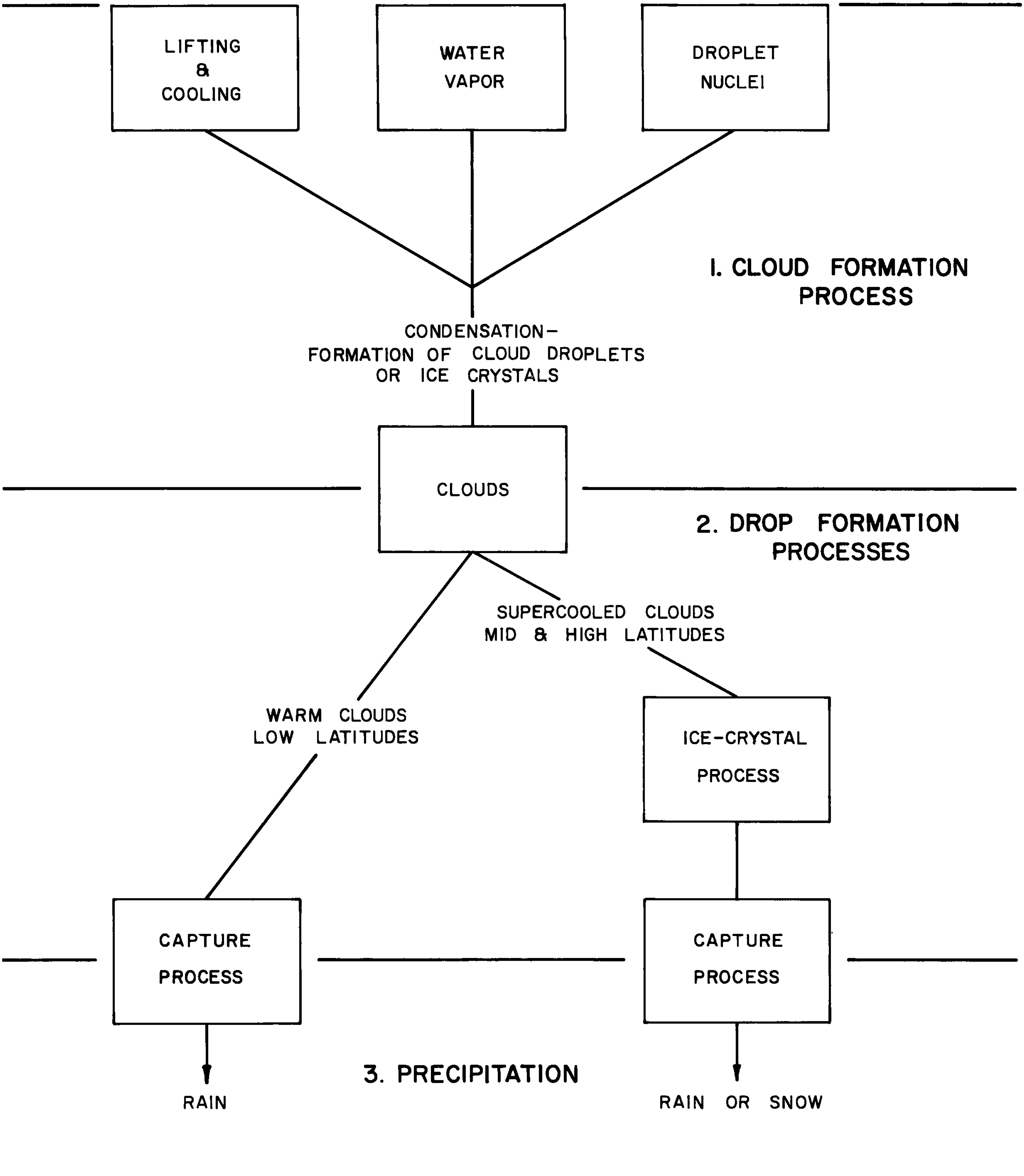


FIGURE 7. PRECIPITATION FORMATION PROCESSES

it cools. Due to the cooling, water condenses on the many condensation nuclei. After the formation of many cloud droplets a cloud develops.

There are three major ways in which air masses are caused to rise. The first is called orographic lifting and occurs when air is forced to rise as it passes over mountain ranges. Such lifting is most pronounced in the western United States.

The second type of lifting is called convective lifting. This is caused by the natural rising of warmer, lighter air from colder, denser surroundings. The warmer air results mainly from the diurnal heating of the land or from cold air moving over a warm surface. Convective lifting is responsible for the summer thunderstorms over New York State.

Cyclonic lifting, the third mechanism, results when a warm air mass from the south encounters a colder mass moving from the north. The warmer air is slowly lifted above the advancing wedge of the cooler air, resulting in cloud formation. The interface between the two masses is called a front. Most of the clouds and precipitation in the eastern United States during the cooler half of the year result from this type of lifting.

Cloud formation is often the result of a combination of more than one lifting mechanism. For example, heavy cloud development and precipitation formation often develops when a front moves over a mountain range (cyclonic plus orographic). Convective clouds are also aften embedded in the cyclonic clouds passing over New York State.

RAINDROP FORMATION

The condensation processes described above do not produce drops large enough for rain. While it takes only a few minutes for a .05 mm cloud droplet to form, it would take about one day for a 3 mm raindrop to form by condensation alone. Since rain often occurs within two or three hours following cloud formation, processes other than condensation must be responsible for the rapid growth of raindrops from cloud droplets. Two processes are presently believed responsible for most raindrop formation. They are called the ice-crystal process and the coalescence or capture process.

Clouds often contain ice crystals in addition to water droplets. Ice crystals do not always form in clouds even though the temperature may be far below freezing. A cloud with a temperature below freezing which contains water droplets is called supercooled. There will be a very few ice crystals in a supercooled cloud whose temperature is between 32° and 10° F. If the cloud should extend into higher altitudes, the temperature will continue to drop until between 10° and -20° F, there will be a mixture of water droplets and ice crystals. Below -20° F there will be more ice crystals than water droplets. The various layers are illustrated in Figure 8.

Ice crystals will not form in supercooled clouds unless they contain a particle of foreign matter called ice nuclei, or unless the temperature drops to approximately -40° F. Temperatures normally encountered in clouds are greater than this, so ice nuclei are needed. Ice nuclei are different than condensation nuclei. They are relatively scarce in the atmosphere. It has been suggested that they are mainly minute clay particles or possibly bits of volcanic dust. Their origin or composition is not positively known.

Most precipitation starts in the cloud layer containing both water droplets and ice crystals. Water evaporates from the droplets and recondenses, as ice on the crystals. In essence, the crystals grow at the expense of the droplets. This is the ice crystal growth process.

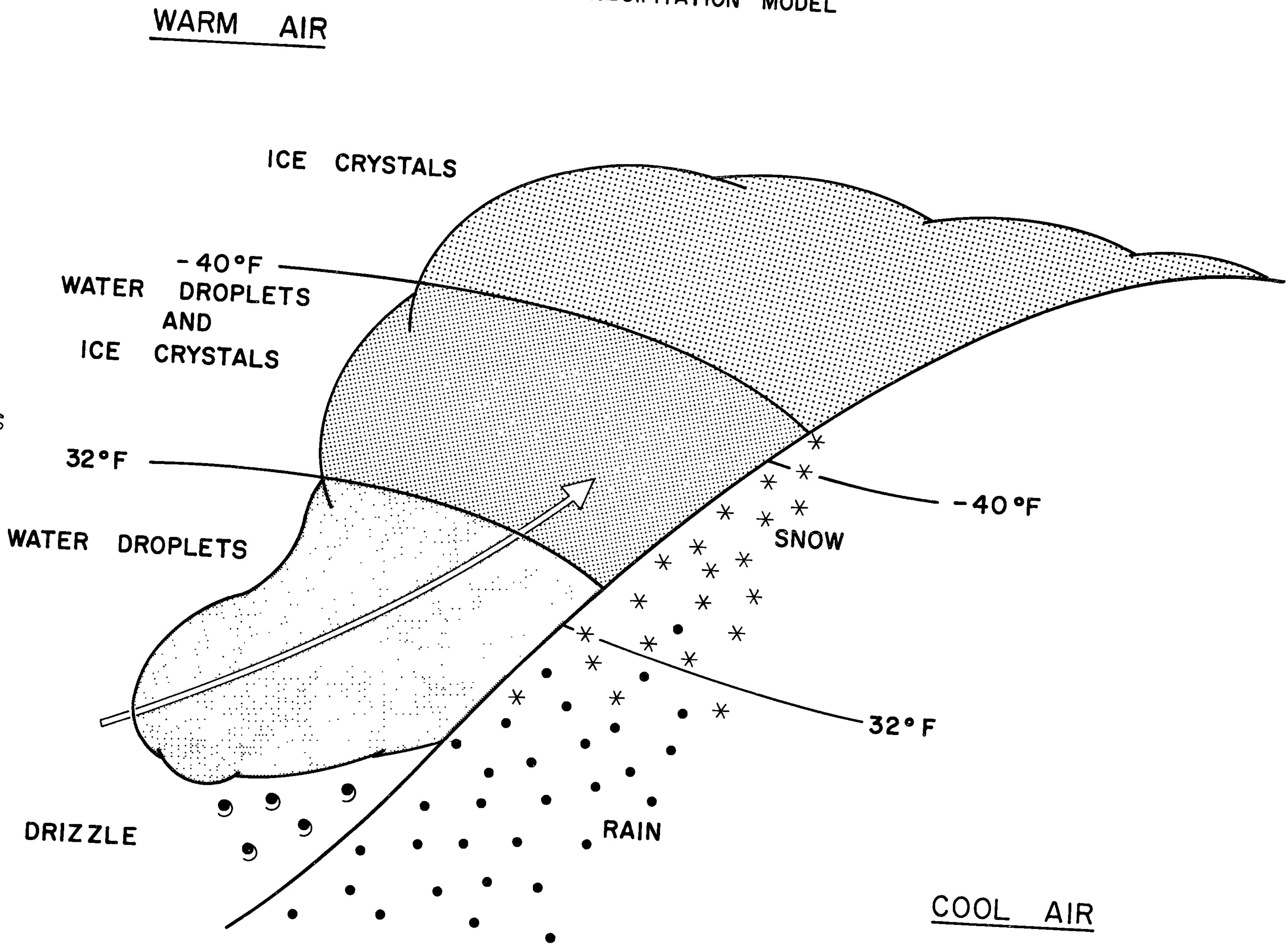
As soon as some of the crystals have outgrown others, they start to fall colliding with other crystals or water droplets. These collisions quite often result in the coalescence or capture of the colliding particles. This is the second type of drop growth process. The particles continue to grow until they leave the cloud. If temperatures are below freezing all the way to the ground, the particles reach the earth as snow. If temperatures are warmer than freezing, the particles may melt and produce rain (see Figure 8).

In high and mid-latitudes raindrop growth forms initially by ice crystal growth with subsequent capture growth taking over. In low latitudes or tropical areas where the clouds do not reach freezing temperatures, raindrop growth results only from the capture process (see Figure 7). This type of cloud exists over Florida and has been successfully seeded there. However, since they do not exist over New York State, they will not be discussed further.

PRECIPITATION MODIFICATION TECHNIQUES

In the previous section the processes leading to the growth of raindrops or snowflakes were discusses. It was seen that a supercooled cloud contains a mixture of water droplets and ice crystals and that the ice crystals grow at the expense of the water droplets. As the ice crystals grow, they start to fall,

FIGURE 8. PRECIPITATION MODEL



colliding and coalescing with other cloud particles. The resulting ice crystals produce rain if they melt before reaching the ground.

The ice crystal plays a very important role in the production of rain. Precipitation is more likely to occur if the number of ice crystals can be increased. Unfortunately, many supercooled clouds contain very few ice crystals due to the shortage of ice nuclei. In cloud seeding, silver iodide particles are released in the atmosphere to act as ice nuclei, causing ice crystals to grow rapidly. This is called the static approach to cloud seeding.

It is believed that the silver iodide particles "fool" the water molecules in a cloud into behaving as if the silver iodide particles were really ice crystals. This is because the molecular structure of a silver iodide particle is very similar to that of a natural ice crystal. In other words, the water molecules react as if the silver iodide were really ice crystals and are attracted to it. Upon contact, the silver iodide functions as an ice nucleus and the water freezes to its surface. Water will freeze to silver iodide at a much higher temperature than to naturally occurring nuclei. This further enhances the efficienty of this particular material.

There are two other cloud seeding techniques. One is used in tropical storms which contain no ice crystals and consequently would not apply to the clouds over New York State. The other technique, dynamic cloud seeding, uses massive amounts of silver iodide particles to seed cumulus clouds. These are clouds formed by convective lifting and develop into the thunderclouds responsible for summer storms. The physical mechanisms behind dynamic seeding are complex and beyond the scope of this paper. Consequently, they will only be briefly discussed. The purpose of this type of seeding is to increase precipitation through invigorated cloud growth. The seeding causes clouds to grow much larger than under natural conditions, thereby increasing the precipitation. Once the clouds have been developed by dynamic seeding, the precipitation processes described in the preceding pages dominate. This technique mainly influences the early stages of cloud growth and not the later processes of raindrop or snowflake formation

HISTORY OF CLOUD SEEDING

The history of contemporary cloud seeding is rather brief. Discoveries at Schenectady, New York, by Dr. Irving Langmuir and Dr. Vincent Schaefer in 1946 serve as the basis for present modification techniques. They found that dry ice exposed to supercooled clouds produced large numbers of ice crystals. Later in the year, Dr. Bernard Vonnegut discovered that both silver iodide and lead iodide were efficient ice nuclei. On November 13, 1946, Schaefer seeded a cloud with dry ice for the first time and produced snow flurries.

One of the first major research efforts, Project Cirrus, lasted from 1947 to 1952. In this project, 225 flights were conducted to observe cloud seeding with dry ice and silver iodide, and to study clouds. The Project's final reports were optimistic, but they still left many questions unanswered. There was clearly a need for more research.

During the early 1950's, commercial seeding operations expanded rapidly throughout the nation, particularly in the western half of the country. In spite of many instances of rain making success, no statistically significant results were obtained. By 1956, commercial seeders had been reduced to about one-fourth of their 1952 peak when seeding was being tried over approximately 10 per cent of the land area of the United States.

In 1953, Congress established the Advisory Committee on Weather Control to evaluate the state-of-the-art of weather modification. The Committee in its final report in 1957 concluded that a 10 to 15 per cent precipitation increase could be achieved by seeding winter orographic storms in the western United States. It was much less optimistic about modification attempts over the rest of the country. In 1957, the National Science Foundation (NSF) became primarily responsible for weather modification activities and interest grew toward investigating the scientific aspects of cloud seeding.

The Federal Bureau of Reclamation started playing a major fole in funding weather modification projects in 1962. The Bureau and NSF carried out numerous cloud seeding projects during the 1960's. The National Academy of Sciences issued a report in 1966, partially in response to a feud between those who were only interested in the practical effects of cloud seeding (increased rainfall) and those who felt modification attempts should be research oriented. The report found that certain types of cloud systems could be modified to produce precipitation increases on the order of 10 per cent. The Bureau of Reclamation is currently the major precipitation modifying agency in the west, with a 1971 cloud seeding budget of $5.6 million. Several other federal agencies, as well as several private groups, are currently involved in cloud seeding on a smaller scale.

There is very little reliable data available on the history of cloud seeding in the eastern United States. Many modification attempts were made by commercial seeders without proper scientific control. Consequently, it is not possible to reliably predict the potential of precipitation modification in the east.

RECENT CLOUD SEEDING EXPERIMENTS

Clouds often are the product of more than one type of lifting. For convenience, however, this discussion will be divided into three sections corresponding to the different types of lifting processes. This categorization is somewhat artificial, but serves a useful purpose in presenting and comparing the results of past experiments.

OROGRAPHIC CLOUD SYSTEMS

There is some cloud formation in New York State due to orographic lifting, although this type of lifting serves mostly to increase precipitation from existing storms. Orographic precipitation falls from storms moving eastward off Lake Ontario as they pass over Tug Hill and the Adirondack Mountains. Storms moving up the Hudson from the south also release extra precipitation as they pass over the Catskills.

Modest but significant precipitation increases have been reported in several instances from seeded orographic clouds in the western United States. In California, increases have been observed in Santa Clara County, Santa Barbara County, Kings River Watershed, and the Lake Alamor Watershed. Stream flows in the Kings River region were increased by about 6 per cent over a ten year period. In Lake Alamor, increases from certain types of storms amounted to 40 per cent, although the more numerous types of storms showed no increase. The average yearly increase was estimated at 5 per cent.[1] A reasonable estimate for precipitation increases from seeded orographic clouds would be 10 per cent.[8] A combination of cyclonic and orographic lifting from a front passing over a mountain range seems to yield particularly large increases when seeded.

CONVECTIVE CLOUD SYSTEMS

Precipitation modification of convective clouds is more complex than for orographic clouds. It is possible to influence precipitation from convective clouds, but it is not possible to precisely predict either the direction or magnitude of the effect. Convective clouds occur throughout the year in New York, although they are more common during the summer months. They form quickly in summer afternoons and often result in thunderstorms.

Experiments with convective clouds over Arizona did not have any effect at all, while the Project Whitetop experiment in Missouri produced a decrease in precipitation of 5 to 10 per cent over a 5 year period. Several other projects, mostly in foreign countries, report success. Clouds were seeded over southern Florida and precipitation increases as high as 100 per cent were observed. These unique tropical type clouds, however, occur only over the Gulf Coast, India, Indonesia, and parts of Australia.

Near Rapid City, South Dakota, experiments produced varied results, depending on wind direction and whether the rain was a result of isolated showers or widespread convective activity. It appears that modification of convective clouds might hold promise for the future, but effects cannot be accurately predicted at the present time.

CYCLONIC CLOUD SYSTEMS

Cyclonic cloud systems are characteristic over New York in the cooler half of the year. They may cover extremely large land areas and consist mostly of stratus clouds.

Few modification attempts have been performed on cyclonic clouds. Current seeding techniques seem more applicable to convective or orographic clouds than to cyclonic clouds. In 1966, the National Academy of Science stated, "There is no clear evidence to date in stimulating precipitation from this type of storm; but little effort has been made except by commercial operations..."[8]

From 1959 to 1963, cloud seeding projects were conducted in cyclonic clouds over Western Quebec. The results were inconclusive, although it was felt there had been a slight decrease in precipitation. On the other hand, for one set of seeding experiments in the Soviet Union, normal winter precipitation reportedly increased about 20 per cent.

It is felt that cyclonic systems have a high precipitation efficiency. That is, most of the precipitable moisture in the systems ultimately becomes precipitation. It might not be possible to increase the total quantity of precipitation, but it may be possible to redistribute. That is, it may be possible to increase rainfall in one location at the expense of another.[8] For example, if a winter storm moving from West to East was seeded and as a result precipitation was significantly increased over New York State, a decrease in precipitation might be expected over New England. New England would be subject to what is sometimes called a "rainshadow". However, Dr. Vincent Schaefer does not feel there would be any noticeable rainshadow caused by cloud seeding in the Northeast.[10] Both increases and decreases have been reported downwind of seeded areas[8], but it is currently impossible to predict what might happen in New York.

In summary, cloud seeding experiments in the West have been moderately successful with orographic cloud systems. For the convective and cyclonic cloud systems which predominate in the northeast, the success of experiments has been less.

ENVIRONMENTAL EFFECTS OF WEATHER MODIFICATION

One of the major concerns in precipitation modification is the "downwind effects" of cloud seeding. Both increases and decreases in precipitation have been reported downwind of prime targets. A decrease, commonly called a rainshadow, might be expected since seeding normally removes additional cloud moisture, leaving less moisture to fall over downwind land area as the cloud system moves on.

In Project Whitetop experiments mentioned earlier, a rainshadow was observed 40 to 50 miles downwind of target. More recently, however, only increases in precipitation have been recorded downwind of target areas. The reason (or reasons) for the increase is currently an area of disagreement among meteorologists.

The effect of cloud seeding on the general ecology of an area is also a matter of concern. Extensive and long range modification projects could bring about moderate shifts in rates of reproduction, growth, and mortality for some living things. The changes will be slow and hardly noticeable, but over a long period of time they could be significant. Ecological changes caused by weather modification are expected to be much less in humid regions than arid regions.

The silver iodide used in cloud seeding operations is a matter of some concern. Silver is potentially toxic in sufficient concentrations. The concentration of silver in water from seeded clouds is about the same as that found is seawater. Iodine from cloud seeding is present in such minor quantities when compared to background amounts that there is no hazard.[3]

Since silver iodide is practically insoluble in water, very little enters the life cycle of plants and animals. Most of the silver iodide which reaches the ground is absorbed by clays or organic matter. It is possible for some reconcentration to take place through biological food chains, but most silver iodide is quickly immobilized in biologically inactive compounds. In this way, silver differs from other heavy metals which are considered dangerous. For example, lead and mercury do not normally form insoluble and inactive compounds; hence, they are considered more toxic than silver. Silver iodide may slightly inhibit the growth of selective types of algae and fungi in fresh water, but will probably have no appreciable effect on fish life.

It currently appears that silver iodide will not adversely affect plant or animal life, even after some 20 years of application. It is recommended that limits of silver iodide concentrations be established and that existing base levels be determined. It will then be possible to observe any increase of silver iodide in water supplies.

In summary, current cloud seeding methods will not have a significant effect on the environment, particularly, in non-arid regions. The changes in both the magnitude and distribution of precipitation is not considered to be of major importance. The use of silver iodide as a seed will not affect plant or animal life.

LEGAL ASPECTS OF WEATHER MODIFICATION

There are few state or federal statutes and few court decisions involving weather modification. The information upon which to base a discussion of the legal aspects is sparse. Questions such as who has jurisdiction over the weather and who has a vested right in rain from cloud seeding projects have not been given much consideration by either state legislatures or Congress.

The following principal problem areas will be discussed: one, the problem of the role of government and statutes; two, the liability problem; and three, the problem of who controls increased runoff.

GOVERNMENTAL STATUTES

Up to now, Congress and the federal government have been primarily concerned with investigating and coordinating weather modification attempts. Proposals to regulate cloud seeding have been considered, but so far none have been enacted. Consequently, at the federal level there are no laws which can be used to resolve disputes arising from modification attempts.

Twenty-nine states have laws affecting weather modifiers. They range from regulatory requirements, such as licensing of cloud seeders, to statutes expressing only an interest in the subject. The state laws lack any sense of uniformity. In Texas, cloud seeders are not subject to absolute liability rules in cases involving private damages.* On the other hand, in Pennsylvania and West Virginia, absolute liability may be imposed in private law suits. In Maryland, cloud seeding has been banned altogether. Other states have comprehensive regulatory programs requiring an operator's license for professional weather modifiers and a permit for each modification attempt.

Legislation just passed in New York is the state's first attempt to regulate weather modification activities. The law requires all modifiers to submit an application before engaging in any activities and to keep detailed records of all operations.

Clearly, additional legislation is needed at the federal level to regulate and control cloud seeding. Such legislation, needed to settle interstate conflicts, should establish standards of liability for damages resulting from weather modification and define the property right for increased water supply. Until then cloud seeders cannot be confident that they are fully within the framework of the law. It does not appear that any rules developed through the common law system will be able to clarify the situation. The court decisions have been too conflicting to allow for any generalization. These decisions will be discussed in the following sections.

LIABILITY DECISIONS

Liability cases against weather modifiers began long before Langmuir and Schaefer made their discoveries which led to modern cloud seeding techniques. One such case took place in upstate New York in the late 1800's. Local farmers were in dire need of rain following a long period of drought. Finally, Reverend Duncan McLeod organized a large community prayer. Three hours later a violent thunderstorm swept the area and a large barn owned by Phineas Dodd was struck by lightning and burned to the ground. Phineas, who was opposed to the prayer in the first place, sued Reverend McLeod for $5,000 for the loss of his barn. Reverend McLeod was spared a ruinous judgement when his counsel argued that the Reverend had prayed only for rain and that the lightning had been an act of God.[7]

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* In cases involving absolute liability, the defendent cannot be sued on the basis that he should have foreseen the consequences. In ordinary liability actions, a defendent is liable on the basis of foreseeability, i.e., in this situation the defendent can predict the outcome and can be held accountable.

The same problem that faced Phineas Dodd, faces plaintiffs today when they try to argue their cases. They are unable to prove the cause-effect relationship, i.e., they cannot prove whether a particular atmospheric condition was a result of seeding of if the condition would have occurred naturally. Since 1950 there have been eight court decisions involving weather modification. In none of the cases involving liability has the palintiff been able to prove the cause.

In three of the eight cases, injunctions have been sought against cloud seeders to prevent their activities. Two cases resulted in injunctions, while Slutsky vs. City of New York an injunction was denied. In 1950, New York City was considering cloud seeding in the Catskills as a means of alleviating a drought. Slutsky, a resort owner, objected to increased precipitation and sought to enjoin the city. Although the weather modification attempts were terminated, the court ruled in favor of the city saying:

> "This Court must balance the conflicting interest between a remote possibility of inconvenience to the plaintiff's resort and its guests with the problems of maintaining and supplying the inhabitants of the City of New York and surrounding areas with a population of 10 million inhabitants, with an adequate supply of pure and wholesome water."*

CONTROL OF INCREASED RUNOFF

Three cases have also spoken on the ownership of additional runoff as a result of weather modification. All three cases give different opinions. These opinions range from the property rights of a landowner to all water contained in clouds, to the Slutsky case which says property owners have no rights in the clouds or to the water contained in them.

PERSPECTIVE ON WEATHER MODIFICATION LAW

Existing laws are inadequate to control all aspects of weather modification. Even where states have laws imposing liability, plantiffs have been unable to prove the cause of their injury. Weather modification is new and the few court decisions rendered have sometimes been contradictory. Common law develops slowly, so there just hasn't been time for a significant body of case law to emerge.

* Slutsky vs. City of New York, 197 Misc. 730, 97 N.Y.S. 2d 238 (Sup. Ct. 1950)

Extensive modification attempts in a population area could result in numerous law suits. Additionally, the outcome of any litigation is a matter of conjecture at this time. It is difficult to find any trends from a study of existing cases. It would be expected that any agency practicing weather modification in southeastern New York would become involved in lengthy court battles.

FEASIBILITY OF CLOUD SEEDING IN SOUTHEASTERN NEW YORK

The lifting process plays a very important role in the formation of clouds. To a large extent it determines cloud type which then influences the cloud's response to seeding. In the "Recent Cloud Seeding Experiments" section of this report, examples of precipitation modification attempts were discussed for clouds formed by each type of lifting. Many orographic clouds have been successfully modified to increase precipitation. Convective clouds have also been successfully modified at least to some degree. Cyclonic cloud systems appear less likely to yield significant increases in precipitation when seeded. In this section of the report, the feasibility of increasing precipitation from some of the more common cloud systems passing over New York State will be discussed.

Almost all precipitation in New York State falls as a result of cyclonic or convective storms. Most precipitation which falls in the cooler half of the year (October-March) is cyclonic in origin, while in the summer most precipitation comes from convective clouds. Each system contributes about 50 per cent of the total precipitation over the state.

The cyclonic storms are responsible for continuously overcast skies frequently experienced during the winter. Precipitation from these storms is relatively steady and usually lasts several hours. Normally, these storms move approximately from west to east. They are often formed along the front between a cooler air mass moving from the northwest and moist, warmer air moving northward from the Gulf of Mexico. During the cooler half of the year these storms frequently pass directly over New York State while in the summer the storm track moves northward. Correspondingly, there is more precipitation over the state from cyclonic storms in the winter than in the summer.

Occasionally thunderstorms occur along the southernmost edge of the summer cyclonic storms. Although a result of convective lifting, they are indirectly attributed to the cyclonic storms.

Clouds formed by cyclonic lifting are generally less favorable for precipitation modification than are the other cloud types. Cyclonic systems are characterized by stratus clouds, which are too shallow and too stable to give significant precipitation increases when seeded.

In New York convective type clouds are usually embedded in the stratus clouds formed by cyclonic storms. Some precipitation increases might be realized from seeding these clouds. However, cyclonic storms in general have a high precipitation efficiency, i.e., most of the moisture that can fall will fall, so there is probably little to be gained from modifying these clouds.

Passage of cyclonic storms over the Great Lakes in the winter results in large amounts of snow falling on the lee (or downwind) side of the lakes. This is particularly true of Lakes Erie and Ontario and accounts for the large snowfalls along the shores of these lakes in upstate New York. It has also been demonstrated that if too many silver iodide nuclei are added to certain storms, precipitation will be decreased or delayed, falling further downwind. This concept has been suggested for application along the Great Lakes.

Under such a plan, snow which normally falls along the shores of the Great Lakes could possibly be made to fall further inland over New York City watersheds. The State University of New York at Albany conducted some very limited experiments in 1968 to test this hypothesis. They felt that the effect of overseeding on the snowfall redistribution concept was very limited. Consequently, this plan does not seem feasible at the present time.[6]

Convective precipitation is characteristic of the warm half of the year. These convective storms originate from semitropical air masses spreading northward over New York State. Localized heating of the ground generates air currents that begin to rise and form cumulus clouds. Brief showers or thunderstorms--measured in minutes instead of the hours of cyclonic storms--often of high intensity are the result of convective lifting. The potential of seeding these storms has never really been investigated. Often the storms are so intense that any increase could result in additional property damage.

Mountains in New York do contribute to cloud formation through orographic lifting. The lifting is not as extensive as in the western United States, but can provide significant precipitation increases from passing cyclonic or convective storms. The Tug Hill, Adirondack, and Catskill Mountains all receive orographic precipitation. Tug Hill and the Adirondacks receive increased precipitation during the cooler half-year from cyclonic storms moving eastward off of Lake Ontario. The Catskills receive orographic precipitation from cyclonic systems moving up the coast in the winter and from convective storms moving northward during the warmer half-year. Seeding of clouds enhanced by orographic lifting has not been investigated in this state.

In summary, the potential of cloud seeding to increase rainfall in New York State cannot be accurately assessed. A study of the cloud systems over New York does indicate that large increases are very unlikely. Small increases might be realized by seeding summer convective storms and areas receiving orographic precipitation.

USE OF PRECIPITATION MODIFICATION TO INCREASE WATER SUPPLY

Our primary interest in weather modification is how it may be used to influence the available water supply in southeastern New York. Computer simulations indicate that, on the average, a 10 per cent precipitation increase might ultimately result in about 10 to 20 per cent increase in water supply. Beyond this, however, there is a real dearth of information on how weather modification can affect runoff, and ultimately, water supply in dry years.

It is not good enough to be able to increase stream flows in average years. We must be able to make more water available in dryer years as well. Cloud seeding can only be done when clouds are present. Often during droughts there are few clouds to seed. The amount of precipitation which can be released from the weak and transient atmospheric disturbances which occur during droughts is usually very small. It appears that alleviation of drought could better be accomplished through wise planning and usage of water storage and distribution systems.[5] The chances of increasing precipitation during wet years when it is not needed are better than during drought years when it is needed.

Both the American Meteorological Society and the United States Weather Bureau maintain that cloud seeding will not prevent nor alleviate droughts. The Interdepartmental Committee for Atmospheric Sciences in a recent report summed up the question of drought relief as follows:

> "It should be noted that the emphasis of the present program of atmospheric water management is directed toward increasing or diverting precipitation from existing cloud systems which nature provides. The alleviation of long-term drought is, unfortunately, beyond the reasonable expectation of these techniques because they require the presence of cloud systems containing adequate water budgets. In many long-term drought situations, the lack of precipitation is caused by the persistance of dry air masses over the distressed area...[8]

Additional runoff must also come at a time when storage is available. Should runoff be increased at a time when all reservoirs are filled to capacity, the additional yield would be wasted. Consequently, since weather modification does not work well during drought periods, it will be necessary to construct additional reservoirs to store added rainfall from previous wet periods for use during droughts. However, the simple increase in storage capacity will, by itself, increase the yield of supply.

Dr. Schaefer has suggested that it may be possible to predict major droughts through long range weather forecasting[10], although we do not have this capability at the present time. By modifying precipitation in the years just prior to a drought, the increased precipitation could be stored for use during the drought. The disadvantage of this proposal is that additional reservoirs will still be needed to store the increased yield. This defeats one of the major advantages of weather modification--the use of existing storage facilities to collect and store the increases in runoff.

The potential of weather modification is limited even if adequate reservoir capacity is available to collect additional runoff. Based on a computer simulation study of the Connecticut River Basin[1], a 10 per cent precipitation increase during an average year over the Delaware watershed would produce an estimated 120 MGD additional water. This assumes that <u>all</u> storms occurring throughout the year are successfully modified to give an increase in precipitation of 10 per cent. It is very doubtful if this large an increase could ever be realized. Nevertheless, even this optimistic estimate of 120 MGD falls far short of the increasing demands of the region.

More realistically, an increase of less than 10 per cent should be expected from weather modification during an average year. During drought years, the precipitation increase would be still less. Consequently, a realistic estimate of increased water supply will be much less than the above optimistic, yet inadequate level of 120 MGD.

ECONOMICS OF WEATHER MODIFICATION

Economic analysis of precipitation modification proves to be very difficult. Increased rain which is a benefit to one party may be a liability to another. For example, in the late 1960's Florida was suffering from a prolonged drought which was harming the ecology of the Everglades and other users of water, including cattle ranchers. A successful cloud seeding program was started, but the target area for seeding had to be moved to keep from damaging extensive strawberry crops in neighboring areas. The cost of weather modification is not confined to the expenditures of the person modifying the weather. The cost of side effects can be very great, although they may be very difficult to predict or determine.

The operational cost of cloud seeding appears very small when compared to the total cost of public water supply. The cost of a potential seeding project covering 10,000 square miles of the Connecticut River watershed was estimated, from computer simulation, at $10 per million gallons (MG).[1] This is only the cost of seeding clouds and does not allow for any collection, treatment or distribution.

The Corps of Engineers has estimated the cost of water, at source, from a conventional reservoir at $38 per MG. If the additional water obtained by precipitation modification could be used directly, a considerable savings could be realized. Unfortunately, precipitation modification is not particularly successful during dry periods and the cost of storage must be added to the cost of cloud seeding. Therefore, it would still be necessary to construct reservoirs to store water. Cloud seeding is only economically attractive if existing reservoirs can be used to store added runoff or if water can be withdrawn directly from streams without any storage. Consequently, although the operational costs of weather modification appear small, there is little economic advantage to cloud seeding because reservoirs will still be needed and the costs of cloud seeding increase during times of drought.

FUTURE OF WEATHER MODIFICATION

Large scale modification of weather patterns appears a long way off. It is currently beyond the capability of man to influence weather on a regional basis. Localized cloud seeding appears promising as a means of increasing natural precipitation under appropriate conditions. Generally, orographic cloud seeding is considered to increase precipitation by 14 per cent. Seeding of these systems will probably continue in the western United States. The effect of seeding convective and cyclonic systems is less clear. It may be several years before it will be possible to dependably modify these cloud systems to increase precipitation. Attempts to modify convective clouds is increasing in the drier portions of the country, however, no attempts have been made over New York State.

There are many more questions than answers concerning precipitation modification. The social, human and economic benefits or costs of increasing rainfall are undefined. The legal and political problems are a deterrent. The downwind effects of cloud seeding are unclear, with either an increase in precipitation and/or a "rainshadow" possible.

Cloud seeding is a developing science. The use of simulation models and computers may lead to a more precise prediction of the effects of cloud seeding. Such models may be able to foresee which clouds can be seeded to produce increases in precipitation, the magnitude of the increase, and the probably downwind effects.

No models have been developed which simulate potential seeding regions in New York State. The facts that little weather modification has been tried here and the lack of models make it impossible to predict the outcome of any precipitation modification attempts in this state.

Air pollution may be slowly and inadvertently modifying the weather over many of the more populated areas of the country. Dr. Schaefer has theorized[10] that lead from automobile exhausts may be reacting with iodine present in the atmosphere to form lead iodide. This compound influences precipitation in much the same way as silver iodide, serving as an efficient ice crystal nucleus. Dr. Schaefer points out that most clouds presently occurring over the Mohawk and Hudson Valleys are composed exclusively of ice crystals and contain no supercooled water droplets. He feels this is due to lead iodide inadvertently seeding the clouds resulting in all supercooled droplets forming ice crystals. With no supercooled dropelts, it is difficult for ice crystals to grow to a size large enough to cause them to start to fall. Furthermore, seeding these clouds would not increase precipitation since there is already an abundance of ice nuclei. It is not known if this situation exists over other portions of the state.

The effect on precipitation from air pollution is unknown. Precipitation from clouds with a small amount of moisture may be reduced. If the clouds contain excess wide-spread moisture, then this inadvertent seeding could result in an increase in precipitation. Consequently, depending on cloud type, precipitation could be either increased or decreased by air pollution.

This discussion reveals one of the major disadvantages of weather modification as a means of augmenting water supplies. The precipitation process is a complicated procedure which is not fully understood. Other unknowns, such as inadvertent seeding by air pollution only tend to further complicate matters. The science of weather modification is in its infancy and has a long way to go before man will be able to understand and predict the outcome of cloud seeding. This unpredictability detracts from the acceptance of weather modification as a means of increasing water supply.

FINDINGS AND CONCLUSIONS

1. The most successful cloud seeding to date has been done in orographic clouds in the western United States. Some success has been achieved with convective clouds, but the results cannot be reliably predicted. Cyclonic systems are the least favorable cloud type for precipitation modification.

2. The cloud types occurring over New York State cannot be reliably modified to increase precipitation.

3. It is difficult to determine exactly how much of the increased precipitation will become runoff and available for water supply. An extensive study will have to be made of the characteristics of each watershed before any estimates can be derived.

4. The effectiveness and reliability of weather modification is lower in dry years than in wet years.

5. In order to increase water supply by cloud seeding, it will be necessary to construct new reservoirs to store added precipitation from wet periods for use during drought.

6. It is not currently possible to predict droughts, hence it would be impossible to determine when to modify the weather in order to increase water storage prior to a drought.

7. There are many costs in addition to operating costs, i.e., property destruction and increased snow removal, which make any accurate cost analysis very difficult.

8. Local weather modification by cloud seeding with silver iodide should not present any large scale ecological changes.

9. The laws controlling weather modification are inadequate. Legislation is needed to define legal activities of weather modifiers.

10. Increases in atmospheric pollutants may be providing sufficient ice crystal nuclei, thus making efforts by man to purposefully seed clouds ineffective.

RECOMMENDATION

Weather modification is not recommended as an additional source of water supply for southeastern New York. The reliability and efficiency of cloud seeding are too uncertain to rely on weather modification to augment a need as critical as public water supply. There is no possibility of drought relief through cloud seeding unless large reservoirs are constructed to store water for use during dry periods.

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FEASIBILITY OF WASTEWATER RECYCLING AND REUSE

Approximately 80% of the water furnished by a public water system ends up as wastewater requiring treatment and disposal. Consequently, the idea of recycling wastewater back into the urban water system has great appeal. It suggests a closed system with only limited need for additional water. The thought is attractive and simple, the reality is complex and difficult.

Recycling and reuse are dependent to a great extent on available technology. Treatment processes are needed to furnish any desirable quality of finished water. Consequently, an investigation into the presently available advanced wastewater treatment processes, both technically and economically, is necessary.

Potentially, wastewater can be recycled and reused for a variety of purposes. This report is concerned with recycling and reuse for public water supply purposes. Both direct reuse and indirect reuse are discussed in this report. <u>Direct reuse</u> is delivery of treated wastewater directly to the point of use. This implies a physical connection between the treated wastewater and the water system. <u>Indirect reuse</u> is delivery of treated wastewater into ground or surface waters which are eventually used for public water supply purposes. However, indirect reuse approaches direct reuse in terms of effect when the outlet of the wastewater treatment plant and the intake of the water system are so close together as to function as a direct connection as could be the case in some instances of both surface and groundwater takings and discharges.

The basic cases of recycling and reuse are:

Direct Reuse

Case I - Inject treated wastewater into water supply distribution mains

Case II - Return treated wastewater to head of water system for reintroduction into water system

Indirect Reuse

Case III - Recharge treated wastewater into underground aquifer by well or surface basin from which water supply is drawn

Case IV - Discharge treated wastewater into stream or river or other surface water with withdrawal for water supply use downstream by another community

The three major elements of concern in wastewater recycling and reuse are covered in the following sections of this report. These are:

- Advanced Wastewater Treatment Processes
- Direct Reuse
- Indirect Reuse

ADVANCED WASTEWATER TREATMENT PROCESSES

INTRODUCTION

The first consideration in wastewater treatment is the quality of the input water. Ordinary domestic sewage is the admixture of human and household wastes and water. This type of input is found in individual houses and small communities. It is readily amenable to treatment.

Sewage from large metropolitan areas is much more complex. In addition to human and household waste, it may contain a variety of waste products from commercial and industrial activities, and surface runoff. Consequently, sewage can contain silt, oils, phenols, acids, alkalies, radioactive material, heavy metal, pesticides, toxic and petro chemical material. Such waste input is variable and difficult to effectively control.

Standard sewage treatment processes are designed to treat ordinary domestic sewage in stages and are designated as primary, secondary and tertiary treatment. The last is new in the lexicon of sanitary engineers. Primary treatment removes floating, settleable and some suspended solids and waste elements related thereto. Removals are in the order of 30 to 50% in terms of suspended solids and BOD, secondary treatment is usually a biological process following the primary stage which removes suspended solids and satisfies oxygen consuming material and stabilizes it. Depending on the particular processes, removals are in the order of 55% to 95% (total removal - primary plus secondary) measured in terms of suspended solids and BOD.

Tertiary treatment is an additional stage or stages which are designed to remove specific material or elements such as suspended and colloidal solids, nutrients, refractory organics, dissolved inorganic substances, and bacteria.

Since there are a number of sewage treatment plants in existence in the region and elsewhere which provide some type of secondary treatment, most studies on the direct or indirect reuse of sewage have been aimed toward the use of tertiary treatment plants or the three-stage approach to treatment. The alternative to this would be a total removal plant which could remove all contaminants in a single process.

Total removal processes are not preferred over the primary, secondary and tertiary chain of processes for several reasons, a) the secondary treatment plants already in existence represent a considerable investment which would be lost were the plants abandoned, b) the total removal processes are generally more expensive, and c) these total removal processes have operational difficulties. A great deal of research and development has been done on these total removal processes because of their application in desalting seawater.

Basically there are four single step (or total removal) processes; distillation, freezing, solvent extraction, and reverse osmosis. Electrodialysis and ion exchange can remove dissolved minerals, but are not considered complete purifiers. (Refer to the appendix for descriptions on the operation of each of these processes.) Distillation, freezing and solvent extraction have all proven too expensive.

Reverse osmosis appears promising, but is not ready for widespread use at this time. Costs of $640 per MG have been reported for complete contaminant removal by reverse osmosis plants with capacities exceeding 50,000 gallons/day.[24] There seems to be general agreement in the literature that further cost reduction and development will be necessary before reverse osmosis becomes a viable single step treatment process. Membranes which do not foul as easily and which remove larger percentages of nitrogen compounds need to be developed.

Total chemical process treatment plants deserve mention, although no plant of this type has been built. Several are currently proposed for construction, however. In this method, conventional primary, secondary, and tertiary treatment are replaced by a series of chemical processes, eliminating the biological processes currently used. Total costs should be comparable to those of existing procedures, although capital costs would be less. The chemical processes require less land area and are easier to control. Although tentative, this type of treatment holds promise for the future.

WASTEWATER CONTAMINANTS

Because total removal processes are still only in the developmental stage, the major technical concern in advanced wastewater treatment is which tertiary process to employ to remove a specific contaminant. Since sewage is 99.9 per cent water, the contaminants are in relatively low concentrations. There are five general classes of impurities in secondary treatment plant effluents. Tertiary treatment processes are used to effect removals of these impurities. The contaminant classes along with the associated removal process are:

1. Suspended and colloidal solids: This material is largely biodegradable, consisting mostly of dead bacterial cells, debris from dead cells and other bacterial waste products. These minute solid particles give the water a cloudy or turbid appearance. They are too small to settle to the bottom and float free in standing water. The concentration will vary widely from one sewage treatment plant to another, but 30 parts per million (ppm) is an average concentration figure.

   A process incorporating coagulation, settling and filtration which closely resembles that used in standard water treatment will remove most suspended and colloidal solids. Lime is added to the secondary effluent causing the minute particles in the water to agglomerate, or coagulate. These particles will then settle to the bottom of large sedimentation basins and clarified water can be withdrawn from the top. The water is next passed through a granular mixed-media filter to remove any unsettled coagulated particles. The mixed-media filter is able to remove fine suspended inorganic material. For large plants, it is economical to calcine the waste sludges from sedimentation and filtration producing lime, which may be reused, and carbon dioxide.

2. Plant Nutrients

   a) Phosphates: Phosphates are a plant nutrient, and in conjunction with other elements encourage algal growths in water. Although not considered a direct health hazard, the resultant algal blooms in reservoirs or impoundments results in color, odor, taste and turbidity. Removal is desired to prevent algae blooms if the water must be stored for any amount of time. About half of the phosphate in wastewater is introduced through the use of household detergents. Removal of phosphates is recommended even if phosphate-free detergents are used since the concentration will still be large enough to cause plant growth.

   Phosphates react chemically with lime in the coagulation process previously described and precipitate with the suspended solids to the bottom. The settling phase thereby reduces two impurities in one step, with approximately 98 per cent of the phosphate being removed.

b) Nitrogen Compounds: Nitrogen, like phosphate, is a plant nutrient. Furthermore, in the form of nitrates it is a direct health hazard to infants.

Nitrogen is present mainly as ammonia or organic compounds in untreated sewage. During secondary treatment most of the organic nitrogen is converted into ammonia and nitrates. Excessive concentrations of nitrate in water have been known to produce a disease in infants called methemoglobinemia. Concentrations in secondary treatment plant effluents are about half the USPHS limit (although often they are much less). Ammonia is not a dangerous contaminant, but does give drinking water an objectionable taste and can react chemically in water to form the nitrate ion. Consequently, removal of ammonia is necessary.

From 50 to 98 per cent of ammonia can be removed by a process called air stripping. Ammonia appears as a dissolved gas in water. When the water is exposed to large quantities of air, ammonia will leave the water and enter the air as a gas. (See the Appendix for a more complete description.) The process has proven workable, but has several operational limitations which indicate that a better procedure is needed. It has the disadvantage that the ammonia discharged into the atmosphere can be collected by rain and returned back to earth. The process does not operate efficiently in freezing temperatures; consequently, it cannot be recommended for use in New York State.

Ammonia may also be removed by ion exchange using a selective type of exchange resin. The process has problems, such as the disposal of an ammonia-rich brine and high costs.[6] Ion exchange has been tried for nitrate removal, but only with limited success for a variety of reasons. The resins developed so far have not shown a high selectivity for nitrates, and regeneration of resins is usually inefficient. In addition, a concentrated, nitrogen-rich brine must be disposed of. Ion exchange does not appear practical for removing either ammonia or nitrates from large volumes of wastewater at the present time. The process will probably be more extensively developed in the near future, with a corresponding increase in its attractiveness.

Nitrification-denitrification, a biological process, has been recently developed and appears promising. The process converts ammonia to nitrates followed by conversion of nitrate to nitrogen gas which is ultimately discharged to the atmosphere. Both steps of the process are biological and can be carried out much like secondary treatment. The process will be incorporated into the new 300 MGD Washington, D.C., sewage treatment plant now under construction. A 1 MGD facility has been operating successfully for several months at Walnut Creek, California. Nitrification-denitrification has been proven for application as a pollution control process. However, its reliability for waters destined for reuse remains to be demonstrated. Based on preliminary estimates, nitrification-denitrification will cost about $32/MG for a 100 MGD plant capacity.

3. Dissolved Minerals (Inorganic Substances): This grouping includes chemicals such as salts, potassium, calcium and iron. The concentration of minerals in sewage is usually about 350 ppm greater than that found in drinking water. The U.S. Public Health Service and New York State recommend a limit of 500 ppm of dissolved minerals for drinking water. Substances such as lead and arsenic, which can be harmful even in very small concentrations, also fall under this heading. Although they are often ignored in reclamation practices, these substances could create a health problem in any recycled water.

   There are currently three tertiary processes available for the reduction of the mineral content of wastewater. Each of the processes is operational and could be used to reduce mineral concentration to an unacceptable level. Reverse osmosis is expensive, with costs from $220 to $240 per MG[3,8]. Ion exchange costs about $140/MG[8], while electrodialysis costs about $120 per MG (all costs are based on a 10 MGD plant.) Electrodialysis units are commercially available and costs are expected to decrease as future production increases. The process can be closely regulated to remove any percentage of the dissolved mineral contaminants. All three processes are briefly outlined in the Appendix.

4. Refractory (non-biodegradable) Organics: All organics which resist biological degradation in secondary treatment fall into this category. Pesticides, some detergents, bacterial waste products, hormones, tannins, lignins, herbicides and many more unknown organics are grouped here. The

effluent from the Lake Tahoe tertiary treatment plant, one of the most advanced in the world, contains 12 ppm of refractory organics. These specific chemicals are unidentified and it is not known if any of them might be harmful. This is after treatment of a raw water collected from a small non-industrial community. The addition of industrial wastes could bring in more refractory organics. In addition to the possible toxicity of wastewater organics, they add taste, odor and color to water. Some of these substances are rather exotic and did not even exist at the time the present day waste treatment processes were being developed.

Absorption of refractory inorganics in activated carbon columns is the preferred treatment. Removals of about 80 per cent are common with a minimum of 7 ppm remaining. It is not known at this time if this 7 ppm contains harmful substances or not. For example, estrogen, a hormone used in birth control pills is an organic compound which may not be removed.

The removal efficiencies possible for each of the first four classes of impurities is summarized in Table 8.[17] These efficiencies have been estimated from experience in both actual treatment plants and research projects.

TABLE 8

EXPECTED PER CENT REMOVALS

(Does not include nitrogen removal)

Impurity	Primary-Secondary	Coagulation-Settling Filtration	Activated Carbon	Electrodialysis
Suspended Solids	90	99	99	99
Phosphate	30	95	95	97
Nitrogen (Nitrate and ammonia)	50	50	55	55
Organics (bio. & non-biodegradable)	80	85	99	99
Minerals	5	10	15	50

5. Biological Contaminants and Pathogenic Organisms: Algae, parasites, bacteria and viruses fall under this heading. Algae can impart taste and odor to water. Reduction of the phosphate concentration currently seems to be the best method of limiting algae growth, although this approach is being questioned. Parasites such as cysts and nematodes do not constitute a significant hazard, but more information would give added confidence. Bacteria can be effectively controlled through chlorination of water. Present treatment (including chlorination) removes about 99 per cent of the viruses in wastewater, but the remaining 1 per cent still constitute a hazard.

   The use of ozone instead of chlorine has been suggested as an improved method of disinfection.[7] Ozonation has been used in many European countries for over 70 years, while in the United States its use is limited because of high cost.[4] Chlorine can be easily and economically used. Ozone does not remain in the water as a residual following application while chlorine remains active for long periods of time and is able to disinfect if the water becomes contaminated following treatment. Ozone can attenuate viruses in two minutes while chlorine requires over 1 1/2 hours to accomplish the same results. It remains to be determined if new types of ozone generators can overcome some of the previous disadvantages and provide a reliable and efficient mechanism of viral disinfection. Despite its more lethal effects, ozonation has not been demonstrated to be 100 per cent effective in killing viruses in wastewater. Until proven, ozonation will remain only another alternative for the future, and cannot be considered the ultimate answer in disinfection. Perhaps a process combining both chlorination and ozonation would be possible and effective.

COSTS OF ADVANCED WASTE TREATMENT

In order to place the economic considerations in perspective, costs estimates were prepared for a hypothetical 100 MGD plant using secondary effluent as input water. Since no plants have been sized up to the capacity used, the costs are speculative. The costs are for finished water at the plant. Additional costs would include equalization and mixing prior to treatment because of the variability in volume and strength of sewage, storage costs after treatment, delivery costs to the point of reuse and further treatment costs. However, the extent of these additional costs cannot be fully determined because the present level of technology is inadequate to produce safe water. For example, no process exists which can kill all viruses. Until a process is developed, there can be no complete cost estimates for direct reuse.

Conventional primary and secondary treatment costs average about $110/MG from a 100 MGD plant. Tertiary treatment consisting of coagulation-settling, filtration, nitrification-denitrification, carbon absorption, electrodialysis and chlorination is estimated to cost about $285 per MG for a 100 MGD plant operating at capacity. This is the total cost for operation, maintenance, and amortization.

The cost breakdown for the individual processes is given in Table 9. It should be reiterated that the costs are speculative, but can be considered a good approximation of the current situation. The cost for tertiary treatment of $285 per MG seems to represent a realistic average of the literature reviewed. Varying costs found in the literature often represent different levels of operation resulting in different percentages of removals. Naturally, the more stringent the requirements placed on a particular design, the higher the costs. Figure 9 shows how costs vary with different size tertiary plants.

Figure 10 is a further refinement of cost estimates and shows how costs vary with the per cent of time a treatment plant is operating. Also shown in Figure 10 are the annual fixed, operating and total costs as they relate to the degree of plant operation. For example, if a plant is operated 20 per cent of the time, the cost of treated water would be approximately $700/MG. If the treatment plant is only operated ten per cent of the time, costs would rise to $1200/MG. These costs are significantly higher than those presented in Table 9, which are based on a plant operating at full capacity 100 per cent of the time.

FINDINGS AND CONCLUSIONS

Advanced waste treatment is in an early stage of application. Problems include variation of input water, the need for a fail-safe system, the effect of small concentrations of contaminants that cannot be removed, the persistence of viruses through the treatment processes, the need to scale up processes and questionable economics. In spite of these problems, continued development is expected so that eventually it should be possible to produce a finished water from wastewater to meet the most exacting specifications. This is not the case at present and probably will not be for some time to come.

Table 9

COST* OF TERTIARY TREATMENT FOR A 100 MGD PLANT

Contaminant Removed	Suspended Solids and Phosphate	Suspended Solids	Nitrogen	Refractory Organics	Inorganic	Pathogenic Organisms	
Process	Coagulation Settling	Mixed Media Filtration	Nitrification-Denitrification	Activated Carbon	Electrodialysis	Chlorination	Total Treatment Costs
Capital (Million Dollars)	8.9	2.1	4.7	12.0	34.0†	--	54.7
Debt** ($/MG)	14	4	7	19	55	--	99
Operation & Maintenance ($/MG)	42	8	25	45	65	1	186
Total ($/MG)	56††	12††	32	64	120	1	285

* Data obtained from reference 10.
** Debt based on 5 per cent for 40 years.
† Cost of electrodialysis as shown is 10 times cost for 10 MGD plant. In reality, cost would be somewhat less for a 100 MGD plant than figures listed. Above cost was used for lack of better estimates.
†† Includes sludge disposal.

FIGURE 9

CAPITAL AND TREATMENT COSTS
FOR VARIOUS SIZES TERTIARY PLANTS

NOTE : I. DOES NOT INCLUDE COSTS
FOR DELIVERY TO WATER SYSTEM

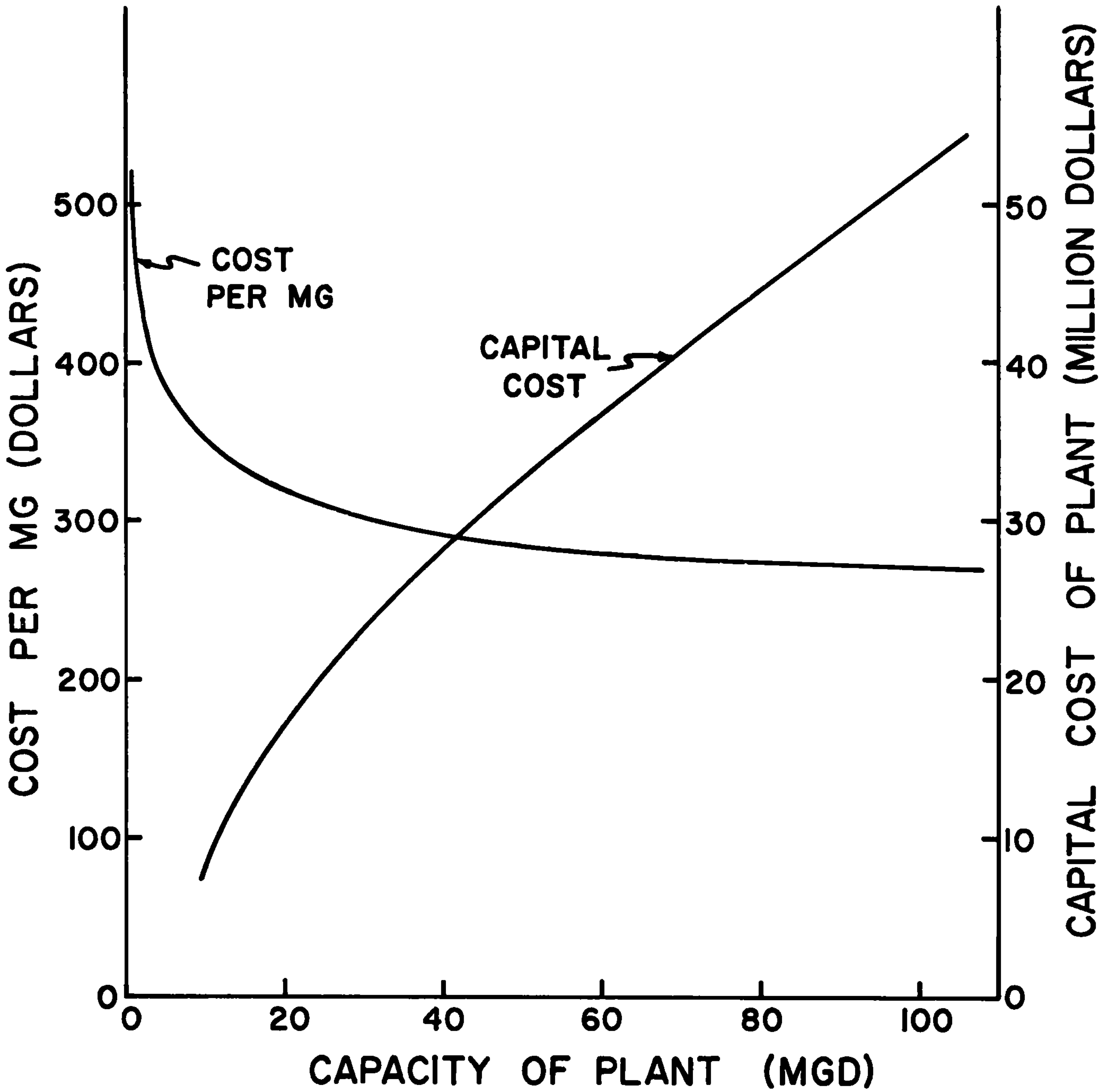
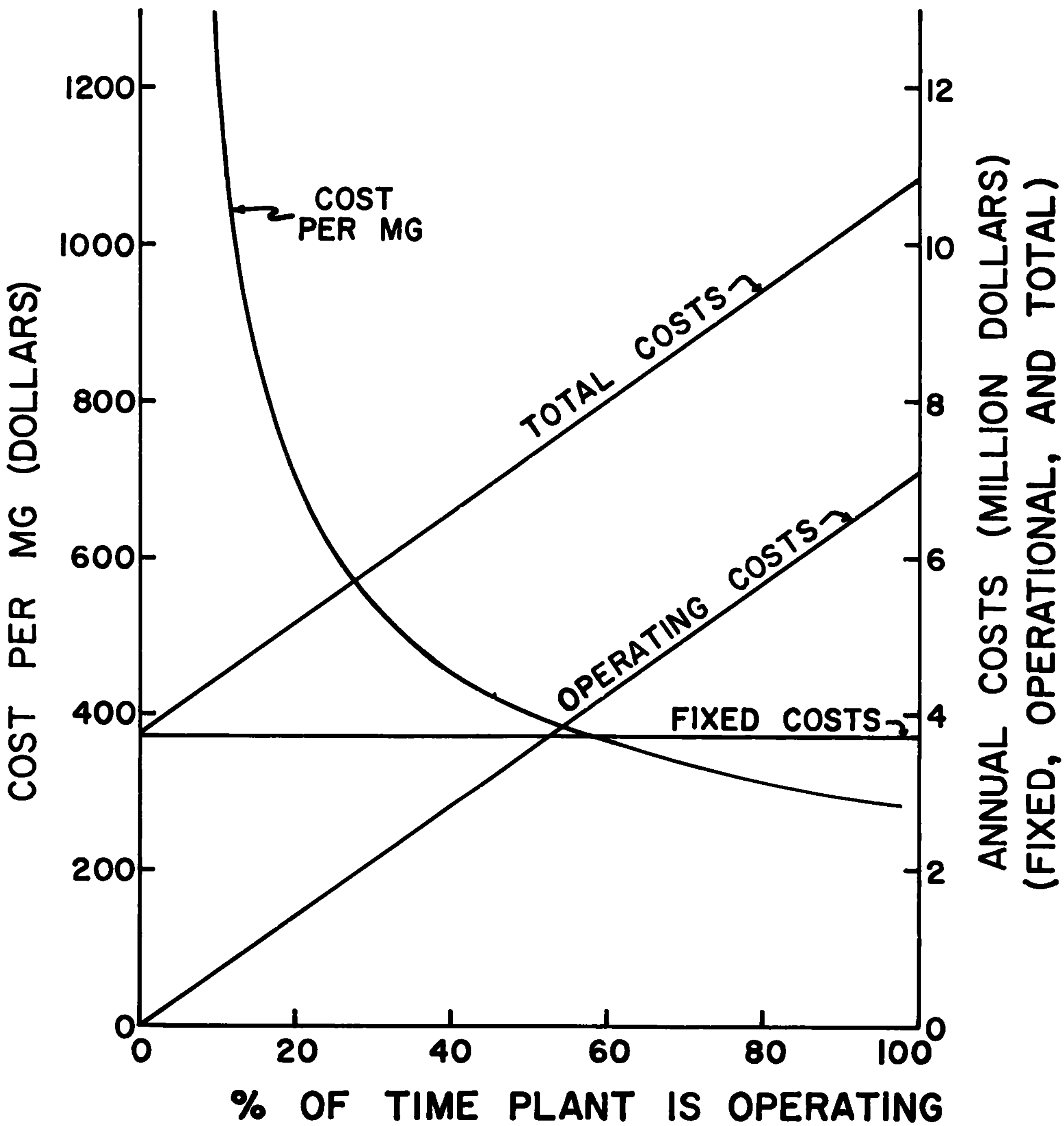


FIGURE 10

ANNUAL COSTS OF 100 MGD PLANT VS. % OF OPERATION TIME

NOTE: COSTS INCLUDE ELECTRODIALYSIS



DIRECT REUSE - TREATED WASTEWATER

INTRODUCTION

Direct reuse of treated wastewater for public water supply purposes has been proposed utilizing two approaches, Case I and II. This would require that, first, an advanced wastewater treatment facility be constructed at an existing secondary sewage treatment plant, and second, that the treated wastewater be 1) injected into the nearest water supply main (Case I), or 2) transmitted to the head of the system for recycling (Case II).

Direct injection, Case I, means that the treated wastewater would be immediately available for use with limited dilution or blending. In Case II, this could also be possible but the opportunity would be present to blend the treated wastewater with natural water to some desired dilution level. The greatest concern is the safety of the consumer. The water furnished must be pathologically safe and free from toxic material. Furthermore, it should be physically attractive and palatable. A discussion of these matters follows.

PUBLIC HEALTH IMPLICATIONS OF WASTEWATER REUSE

SUSPENDED SOLIDS AND NUTRIENTS

The contaminants found in wastewater and the tertiary process available for their removal have been discussed under Advanced Wastewater Treatment Processes. Processes to remove suspended and colloidal solids are available and operate efficiently and effectively. Phosphates can also be removed. Ammonia and nitrate removal processes are available and appear promising, although their reliability remains to be proven. Nitrification-denitrification should soon be developed to the point where it is as reliable as secondary treatment. It appears that the removal of plant nutrients can be accomplished in future reclamation facilities.

DISSOLVED INORGANICS

Dissolved inorganics as a group do not pose any significant threat, and removal procedures are available. The one area of concern involves substances such as lead, mercury and arsenic which are toxic in extremely small doses. The best way of controlling these harmful substances is by eliminating their source. Since they are often found in industrial discharges, industrial wastewater should be sewered separately and not allowed to reach the reclamation plant. This would largely eliminate many of these toxic materials from the reclaimed water.

Inorganics present in small amounts do not present any health hazard nor do they make the water any less desirable. New York State and the United States Public Health Service (USPHS) recommended a drinking water limit of 500 ppm for dissolved inorganics concentration. It is possible to keep the inorganic concentration below 500 ppm by blending reclaimed water with raw water. Figure 11 shows the inorganic concentration of the blended water for varying percentages of reclaimed and raw water. Assuming a raw water quality of 60 ppm, a maximum of 56% of the blended flow could be reclaimed water before the inorganic limit would be exceeded.

The three categories of contaminants discussed so far do not pose any large threat to the health of the users of wastewater <u>provided</u>:

1. Existing removal processes are rigidly applied.
2. New processes such as nitrification-denitrification prove reliable and effective.
3. Disposal of small amounts of toxic inorganics into existing sanitary sewers is prohibited.

ORGANICS

The remaining two categories of contaminants, refractory organics and pathogenic organisms, do pose a significant health threat even if the above conditions are met. It is not possible to remove all organics using activated carbon. The composition and toxicity of the remaining fraction is not known. <u>Studies concerned with the identification and toxicity or organic compounds not removed by activated carbon have hardly begun.</u>

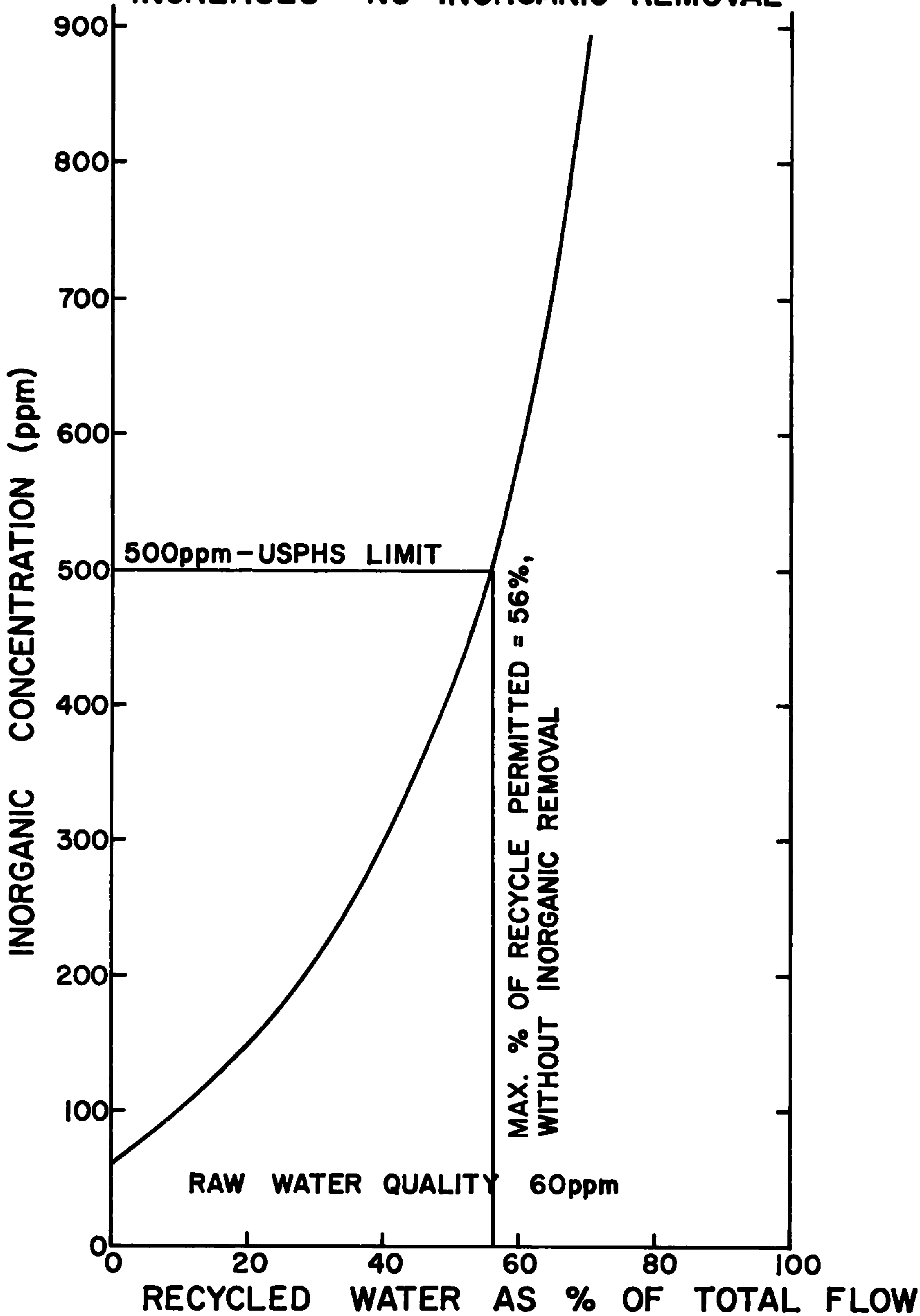
Ottonboni and Greenberg[16] observed tumors in rats which had been permitted to ingest reclaimed water. Following a preliminary investigation, they felt that trace organics might have been involved. They recognize the difficulty in extrapolating from animals to man. The study does point out, however, the large number of unknowns involving organics in wastewater and the possible toxicological effects of ingesting these substances.

VIRUSES

Direct recycling of water containing viruses could result in contamination of the water supply. Viruses may survive for long periods of time in a water supply and can be transmitted by drinking water, but they don't seem to multiply in water systems. Water is not currently important in transmission of viral diseases as

FIGURE 11

CONCENTRATION OF DISSOLVED INORGANICS IN WATER DISTRIBUTION SYSTEM AS RECYCLING INCREASES — NO INORGANIC REMOVAL



most infections result from other types of transmission. This is most likely due to rigorous water sanitation practices, which include acquiring raw waters with a low viral load.[9] There is a definite lack of knowledge in detecting, identifying and enumerating viruses in water samples. Until these information gaps are filled, it is impossible to precisely predict the potential hazards of viruses involved in wastewater reuse. It is generally agreed that presently known treatment processes do not remove all the viruses. Disagreement revolves around the probability of hazard after treatment.

Before water can be considered virologically safe, it is necessary to:

1. Determine the number of viruses remaining after tertiary treatment.

2. Develop an improved method of disinfection.

3. Develop a procedure to monitor the reclaimed effluent to insure that there are no process failures allowing viruses to enter the water system.

Viruses which pass through a renovation plant probably pose the greatest threat to consumers. It is currently impossible to remove or kill all viruses with tertiary treatment. To illustrate the potential danger of viral contamination, instances of viral infections caused by water obtained from more conventional sources have been recorded.

Normally, bodies of water accepting sewage provide a large dilution and a large detention time. If the water is subsequently withdrawn for use, there are very few active viruses remaining as a health hazard. This allows the use of the Hudson River as a water supply source. However, Long and Bell[15] report that the regular low level transmission of viruses from existing water supplies must be considered a source of endemic disease occurrence. They report that "the endemic threat of viruses derives from certain key factors:

1. The infectious dose of viruses is very low...

2. Clinical illness is observed in only a very small fraction of those who become infected...

3. One strain of virus may produce illnesses with widely different incubation periods and clinical manifestations...

4. The killing rate of chlorine for viruses is variable and generally much slower than for bacteria...

...it can be seen that considerable health damage may be occurring from viruses in drinking water without readily being identified."

If it is impossible to eliminate all threat of viral contamination from present water supplies, it is certainly illogical to believe that there is no health hazard involved with direct reuse. Based on the presentation of Long and Bell[15] approximately 1200 people would be infected daily by viruses from ingesting reclaimed water from a 100 MGD source. These people could then, in turn, spread their viruses to others throughout the community by personal contact.

The testing procedures currently available for determining the presence of viruses are lengthy, insensitive and take weeks to complete. In addition, if only very few viruses are present, they may not be detected. Obviously, a better means of viral testing is required. A simplified procedure would make it possible to set limits on viral concentration. Once limits had been established, treatment processes can be evaluated in terms of their effectiveness in meeting limits. However, until a good test is devised, it is impossible to determine the adequacy of existing tertiary processes. Research and development of a viral test should begin immediately.

DRINKING WATER STANDARDS

The fact that renovated wastewater meets or exceeds all limits recommended by the Federal Drinking Water Standards does not mean that particular water is safe for consumption. Implicit in these Standards is the assumption that the best source of water supply should be used. As stated in the Drinking Water Standards for 1962[19]

> "Polluted sources should be used only when other sources are economically unavailable and then only when the provision of personnel, equipment, and operating procedures can be depended upon to purify and otherwise protect the drinking water supply continuously..."

The current state of the art does not allow this degree of certitude with tertiary treatment.

RELIABILITY

The reliability of wastewater treatment processes is subject to question. The biological processes can be particularly hard to control. In 1964, thirty-three per cent of the sewage treatment plants in central California were temporarily inoperative and by-passed raw sewage directly into the receiving waters[13] for periods ranging from 6 hours to 350 days. Although this experience may be atypical, it illustrates that a great deal of work remains to be done to upgrade the operational reliability of existing primary and secondary treatment plants. Tertiary treatment plants are more complicated and will require even more sophistication in operation. For adequate public health protection, fail-safe treatment processes and effluent monitoring devices must be developed. As long as it is necessary to construct treatment plants with by-passes, the reliability is inadequate for direct reuse.

PROPOSAL

In August 1965, a "Proposal for Augmenting New York City Water Supply Through Waste Water Purification and Reuse" was prepared by the Division of Water Supply and Pollution Control of the U.S. Department of Health, Education and Welfare. This proposal recommended the direct injection of treated wastewater into the city distribution system. Although the proposal was never officially adopted by the department, it received wide currency, and was cited in testimony by the Presidents' Science Advisor before a Congressional Committee considering the Northeast drought crisis. The proposal has been repudiated by the Water Supply Bureau of the Environmental Protection Agency. A letter from the present director of the Bureau concerning this proposal is included in Appendix B.

EXAMPLES

Probably the most frequently discussed direct water reuse situation occurred in Chanute, Kansas. This city of 12,000 acquired its drinking water from a river which ceased to flow during the summer of 1956 following a 5-year drought. The city considered several emergency proposals but finally decided to recycle its treated sewage water. Water from the secondary treatment plant was discharged to the river where it was impounded for 17 days before passing through the water treatment plant. This recycling process continued for 5 months. The inorganic concentration in the water system increased from the normal 200 to 500 ppm to 1000 to 1200 ppm. Due to high levels of chlorination, no bacteria were found in recycled water. There were serious color and odor problems and froth developed on the surface of the water. Viruses were found in the treated sewage, but none were found in the treated water. No diseases were ever traced to the ingestion of this water, but it cannot be concluded that the water was pathologically safe, that is, contained no viruses. The recycled water was rejected by the populace and bottled water was imported for drinking and cooking purposes. Local food processing industries also imported water via tank trucks.

It would appear that the Chanute case has assumed an importance in promoting direct reuse all out of proportion to the real situation. It involved a very small non-industrial community in an acute emergency, justifying drastic action. The water produced was unacceptable, rejected by the community, of poor quality and of questionable safety. The only thing of positive note is that no acute water borne disease outbreaks occurred.

The single treatment plant where water is introduced directly to the water supply is at Windhoek, South Africa. Windhoek, located in a water-short area, has been acquiring a portion of its water supply from renovated domestic sewage since 1968. The tertiary treatment plant rivals the one at Lake Tahoe. The cost of the treatment is about $280 per MG. Activated carbon is used to remove the organics--tastes, colors, odors along with insecticides and pesticides. Many viruses are also removed. Maturation ponds are used to hold the water for several days following treatment. It is believed by some that such ponds further reduce the viral content of the water.[6] Industrial wastes are collected in separate sewers and not treated with the domestic wastes. Hence, there is no danger of industrial effluents influencing the water quality.

There is no inorganic or nitrogen removal at Windhoek. Inorganic concentrations are controlled by mixing treated water with fresh water. By mixing treated water of high concentration with raw water of low concentration, a combined water of moderate concentration is produced. The project has the capacity to furnish about 1/3 (or 1 MGD) of Windhoek's water supply. However, the treatment facility is shut down during much of the year because of a high chlorine demand, making continual operation uneconomical. Additionally, the plant is primarily research oriented and the operators are highly skilled, many possessing advanced degrees.

The Windhoek experiment is a modified direct use application. The treated wastewater is returned to the head of the system, stored in ponds for thirty or more days, diluted with natural water, and used for only a portion of the year. It includes the safeguards of selected water input, of natural purification, dilution and storage time.

PUBLIC ACCEPTANCE

One concern about wastewater reuse is that it would not be accepted by the public. Bruvold and Ward[4] did a preliminary study of public attitudes regarding the use of renovated wastewater. They surveyed people in two towns, one in a dry region of southern California and one in a wetter, northern area. Santee, the city in southern California, has a small lake of renovated wastewater which was used for swimming. Of those surveyed in Santee, 64 per cent were not opposed to the use of renovated water for drinking. In the northern city, 44 per cent were not opposed.

These preliminary results have several limitations, and consequently cannot be considered to represent the attitudes of the general populace of the southeastern New York region. The number of people interviewed was small and attitudes concerning water are quite different in California, because of the relative scarcity of water, than in New York.

Two months after the preliminary survey, the original respondents were questioned a second time regarding their attitudes toward the use of renovated water. This time those opposed numbered less than the first time. The reason for the shift in attitude was attributed to discussions the respondents had with friends and relatives following the first interview. After pondering for a while, many persons became more receptive to the idea of drinking renovated wastewater.

Bruvold is currently expanding his study to obtain a better understanding of public attitudes. Results from this study indicate that 56 per cent of the people surveyed in ten California communities will not accept renovated wastewater for drinking.

The work of Bruvold indicates that public opinion is not decidely against water reuse. Further, he demonstrated that the opinion is flexible. There has been no public opposition to direct water reuse in Windhoek and other reporters have recently observed a more receptive attitude towards reuse in this country.[10,18]

ENVIRONMENTAL PROTECTION AGENCY STATEMENT

The United States Environmental Protection Agency has recently issued a statement on wastewater reuse.[20] This statement is reprinted here since it provides an excellent perspective of the health problems related to direct reuse. (A more complete statement is included in Appendix B.)

> "The concurrent use of the Nation's rivers and lakes for both municipal water supply and waste disposal has been practiced for many years in many areas of the country. It is estimated that 50 per cent of the Nation's population now derives their water supply from surface sources which have also received a variety of industrial wastes, untreated sewage, urban runoff and effluent from a variety of sewage treatment

plants. Public health officials have relied upon time of travel or storage and treatment to protect the public against infectious diseases and toxic substances. Water quality standards and treatment requirements applicable to surface sources used for water supply permit the discharge of relatively high quantities of wastes.

Indirect reuse for municipal public water supply is a fact of life; however, direct reuse is a new matter requiring careful research and investigation before introduction.

Health problems in a direct interconnection or in a recycling situation relate to viruses, bacterial build-up, chemical build-up, the possibility of accidental spills or sabotage and a questionable record of reliability in the operation of wastewater treatment plants. Viruses are difficult to identify and measure and are more resistant to disinfection than bacteria. Carbon columns and other possible advanced waste treatment elements may harbor bacteria and contribute to the development of unhealthful levels of bacteria in a recycling situation.

The direct introduction of chemicals from a waste-stream and their buildup through potable system-waste system recycling can present increased long-term chronic hazards, presently undefined. Accidental spills or sabotage present an acute threat which cannot be disregarded, as anyone can throw anything down the drain; some system of holding and dilution reservoirs may need to be provided between the reclamation plant and the potable water intake together with biological and chemical monitoring. With regard to the reliability of reclamation plant operation, studies in California have shown that 60 per cent of wastewater treatment plants studied had some breakdown during the year. Observations of engineers and others confirm that reliability is a common problem in wastewater treatment plants; safeguards must be provided to prevent the introduction of non-treated or poorly treated wastes into a potable water system.

For the above reasons, EPA does not support the direct interconnection wastewater reclamation plants with municipal water treatment plants."

FUTURE OF WASTEWATER REUSE

During 1969, 43 water reuse research projects involving approximately $2.75 million of federal funds were being conducted in the United States. Industry, state agencies and universities contributed additional funds. Major projects investigating tertiary treatment are being conducted at Alexandria, Virginia; Pomona, California; and Lebanon, Ohio.

The present level of technology is inadequate because it does not satisfy the following requirements:

1. Removal of all toxic organics,

2. Removal or destruction of all viruses,

3. Existence of waste treatment processes of proven reliability, and

4. Existence of a method of monitoring renovated water to insure its quality and safety.

Present tertiary processes are few in number, limited in variety and contaminant removal ability, and have not been optimized. In theory, renovated wastewater could be put to any use; but economics, quality control, reliability and lack of monitoring techniques presently preclude direct reuse for drinking. The American Water Works Association (AWWA) issued a policy statement in October, 1971, which recommended limited reuse, but not direct potable reuse because of a lack of scientific knowledge and technology.[1] The California State Board of Public Health established standards for nonpotable wastewater reuse, i.e., for irrigation, recreation and industrial uses. They agree with the AWWA that standards for domestic reuse cannot yet be determined since wastewater constituents, treatment efficiencies and positive control mechanisms for assured public health remain to be established.[14] The AWWA recommends the following research and development projects:

1. Identify contaminants.

2. Determine extent of removal using current processes.

3. Determine long range physiological effects of continued reuse.

4. Develop analytical testing procedures.

5. Determine allowable contaminant limits.

6. Develop monitoring systems.

7. Improve equipment capability and reliability.

The Environmental Protection Agency released a statement in November, 1971, in which they concluded "many health-related questions remain to be answered before unlimited personal use of renovated wastewaters can be an everyday occurrence."[21] Their conclusions and recommendations closely parallel those of the American Water Works Association.

Despite this seemingly large information gap, a concerted effort should close it rapidly. The basic processes and information are known; they need to be expanded and more extensively developed. Exhibiting confidence in the ability to solve technical problems, the City of Denver has committed itself to reclaiming water for human consumption. Funds for a 40 year research and development program have been allocated and by 1985, a 100 MGD reclamation plant is planned for construction. A program evaluating public attitudes along with orientation towards reuse is included. A preliminary public opinion sample shows that about 50 per cent of the population of Denver would approve of reuse.[23]

FINDINGS AND CONCLUSIONS

1. There has never been a Case I application of direct reuse in the United States.

2. The introduction at source application (Case II) is limited to one instance of a highly specialized and experimental nature.

3. The technology of wastewater reclamation is still developmental with many problems to be solved.

4. At this point in time direct reuse represents an uncalled-for risk.

5. Existing advanced waste treatment processes are not able to ensure complete removal of toxic inorganics, toxic organics, and viruses.

RECOMMENDATIONS

1. Direct reuse of renovated wastewater is not recommended as a means of supplementing public water supply because of the danger to consumers. The following major considerations contribute to this decision:

    a. Processes capable of removing all the viruses from sewage have yet to be developed.

    b. It is not known which organic compounds are removed in tertiary treatment, nor the effect on users if some of these compounds should pass through the treatment plant.

    c. The reliability of wastewater treatment processes is subject to question. Biological processes are particularly difficult to control.

    d. Techniques to monitor the treated wastewater are needed, thereby revealing improperly treated water in the event or process failure.

2. Direct reuse of renovated wastewater is not recommended for the Southeastern New York Region. It is not feasible, either technically or economically. The needed technology and knowledge are still lacking. Removal processes need further development to increase reliability and optimize design. Systems to remove viruses and to monitor treated water quality must be developed.

   It is presently impossible to establish a time frame when direct reuse will be feasible.

3. It is recommended the United States Environmental Protection Agency expand research into wastewater reclamation. The cooperation and assistance of state and local agencies should be utilized whenever possible.

INDIRECT REUSE

INTRODUCTION

Indirect reuse is the use of surface or groundwater resources for water supply purposes as well as for wastewater disposal. The distinction between direct reuse and indirect reuse can be obscure. As noted in the introduction, if water intakes and wastewater outlets are not carefully located both in surface and groundwaters, indirect reuse can become direct reuse and have the limitations of direct reuse as developed in the previous section.

Another form of reuse now being practiced in many places is to use treated wastewater for non-potable purposes such as industrial water supply and irrigation. This practice would be of limited value in the Southeast region because industrial and irrigation water demands are a relatively small part of the total water demand, and frequently other suitable water is available.

SURFACE WATER

Indirect reuse of treated wastewater after being discharged into a surface water body is a common occurrence. It has been practiced throughout the world, the nation and in New York State for decades.

Examples of indirect reuse and recycling are common in New York State. A few examples are: Buffalo and Erie County use Lake Erie; Niagara Falls and Niagara County use the Niagara River; Syracuse, Onondaga County, Rochester, Monroe County and Oswego use Lake Ontario. Binghamton uses the Susquehanna River; Elmira uses the Chemung River; the Town of Colonie uses the Mohawk River. On the main stem of the Hudson River, water supply intakes are located at Port Ewen and at Highland in Ulster County, at Poughkeepsie and Chelsea (the emergency intake for the City of New York) in Dutchess County.

Use of surface water for both waste discharge and water supply is possible because the effect of wastewater is considerably ameliorated by high dilution, natural purification, and storage or transit time. This means that there is no build up of contaminants because there is a continuous input of fresh water, pathogenic bacteria and viruses die off through time, biodegradable fractions are reduced to stable compounds, silt and other inert solids settle out, pH is buffered toward neutrality, natural chemical reactions induce precipitation, settling and stabilize compounds, and physical factors are improved.

GROUNDWATER

The other alternative for indirect reuse is to recharge groundwater aquifers with renovated wastewater. Groundwater aquifers suitable for recharge are limited in the Southeast region to Long Island. Consequently, the following discussion will focus on recharge of the groundwater on Long Island with treated wastewater.

Use of groundwater for both water supply and wastewater disposal is possible because of the protection afforded by natural treatment as wastewater moves through the ground, by storage or retention time which allows natural purification to take place, and by limited dilution.

There are, however, some problems associated with groundwater recharge. Wastewater discharged into groundwater undergoes very little dilution, it travels very slowly to a point of withdrawal and consequently, some contaminants may persist for years once put into the ground. Certain dissolved contaminants, organics and inorganics, are unaffected and remain in the water, and dissolved material will slowly build up as recycling takes place.

This means that the overall plan for water supply development and the particular location of water supply wells and wastewater recharge areas are critical in undertaking a recharge and reuse program.

Reuse and recycling of wastewater has been practiced for years on Long Island. About 2,500 recharge wells and 2,000 recharge basins already exist on Long Island to return rainfall, runoff and spent cooling water to the ground. Most of the water pumped on Long Island has been returned to the groundwater by cesspools. This has caused the groundwater quality in the upper glacial aquifer to deteriorate, primarily due to increased nitrate concentration. There have also been problems of color, taste, odor and foaming resulting from detergents discharged with household sewage. Some toxic industrial wastes that have been discharged through cesspools and recharge basins have persisted for years as they slowly moved through the aquifer.

This problem of groundwater pollution has been met by 1) abandoning the upper glacial aquifer in favor of deeper wells into the magothy aquifer, 2) sewering areas of dense development and transporting the sewage to shoreline treatment works for ocean discharge, and 3) prohibiting the sale and use of detergents in Suffolk County.

Simply going deeper means that the polluted horizon of groundwater will go deeper and deeper. Sewering with ocean outfalls results in a permanent negative draft on the groundwater. This has been demonstrated in Kings and Queens Counties.

Many years ago Kings County was sewered and water supply was furnished from the groundwater. Massive water mining took place and resulted in lower water tables and cones of depression which allowed salt water intrusion. Eventually, the groundwater supply had to be abandoned and the area was served by upstate water from the New York City system.

In Queens two large areas continue to be served by private water companies, the Utilities and Industry Corporation, and the Jamaica Water Company, both of which use groundwater sources. Both of the service areas are sewered. The Kings County experience is now being repeated in Queens County. Water is being mined, cones of depression some 30' below sea level have resulted, and the water quality is rapidly deteriorating. To alleviate the situation New York City has agreed to furnish upstate water to U & I. Jamaica Water Company has also proposed buying water from the City.

To avoid the effects of sewering experienced in Brooklyn and now occurring in Queens it may be possible to recharge renovated wastewater to the groundwater rather than discharging to the ocean. There are four major factors to consider in groundwater recharge, 1) mechanical, 2) water quality, 3) economic and 4) institutional factors. Mechanically, the major problem is the clogging of deep injection wells. This phenomena is not well understood. Experiments to date with deep injection wells using renovated sewage have not been successful. This will limit the recharge capability of deep injection wells until the problem is solved. This does not constitute a problem in other methods of groundwater recharge.

Water quality problems are related to toxic inorganics, nitrates, and the build up of dissolved inorganics. To minimize these problems rigid control over toxic wastes collection, treatment of all wastewater, effective nitrogen removal processes are necessary. Dissolved minerals can be removed with present technology as needed.

The economics will vary depending on what type of management scheme is followed. The institutional aspect simply means that the responsibility and authority to regulate, plan and implement must be firmly established at the State, Regional and local level to develop and carry out a program.

Sewers are being constructed on Long Island to eliminate pollution of the groundwater. To recharge wastewater with undesirable contaminants would defeat the major objective of sewer construction. High concentrations of nitrate introduced to the groundwater by cesspool discharges and fertilizer application have been found on many parts of Long Island. Nitrogen and nitrate removal will be necessary before wastewater can be safely recharged. To recharge wastewater without removing nitrogen compounds, would not be much different than allowing cesspool disposal to continue.

Public health hazards from the recharge of renovated wastewater (including nitrogen removal) are minimal. Indirect reuse following recharge allows for a margin of error in the destruction of pathogenic viruses. If viruses are not totally removed by tertiary treatment, those remaining are largely removed as the recharged water filters through the soil. It is generally assumed that some purification results as recharged water moves through an underground aquifer. Depending on the individual circumstances, this may not always be the case, but generally quality does improve. Most importantly, indirect reuse following aquifer recharge provides a time delay before the water reaches a consumer.

The possibility of recycling and reuse through groundwater recharge on Long Island should be closely looked at. The alternative is to follow the historical pattern of Kings and Queens Counties requiring the importation of water from upstate surface sources. It is possible recycling and recharge plus the conjunctive use of upstate water with the groundwater basin on a regional basis would be indicated.

There are several advantages to increasing the water supply through groundwater recharge. First, a large reservoir, capable of storing vast quantities of water is available underground requiring no massive construction projects. Second, the development of the resource can be carried out in stages. Third, as the water moves through the aquifer, certain aspects of its quality may be improved through various interactions with the soil. Observations in southern California have revealed that bacteria and viruses are removed as recharged wastewater moves through the ground.[2] This is why discharges from cesspools do not biologically contaminate the groundwater. Finally, water stored in the ground is not subject to large losses through evaporation.

The New York State Department of Environmental Conservation released a statement on January 3, 1972, proposing that recharge of 50 per cent of wastewaters in Nassau and Suffolk counties be required by 1980 to protect drinking supplies, water resources, and the ecology of Long Island. Commissioner Henry L. Diamond said,

"...we are proposing that 50 per cent of all collected wastewater be recharged by 1980, with treatment that will remove more than 99 per cent of the pollutants." By January 1, 1990, the percentage of recharged treated wastes would be increased to the maximum feasible amount.

STATUS OF GROUNDWATER RECHARGE TECHNOLOGY USING RENOVATED WASTEWATER

Wastewater can be recharged by 1) surface basins, 2) injection wells, 3) stream discharge and 4) spray irrigation.

For convenience, the following discussion will be separated according to method of recharge. The associated objectives and/or effects from each type of recharge will be stated. The current technical status and the inter-relation of water quality will be discussed.

RECHARGE INTO BASINS

OBJECTIVES

The major effect of basin recharge is to raise the groundwater table. A higher water table will subsequently increase streamflow and groundwater underflow to sea, and raise the water level in lakes and ponds. This will help to satisfy the needs of ecology, recreation and esthetics.

Basins will recharge directly into the glacial aquifer. If the recharge basins are located outside a narrow strip of land located about half way between the north and south shores, a large portion of the recharge will flow through that aquifer directly to the sea. Lesser amounts will reach the Magothy and other deep aquifers.[5] This is because horizontal permeabilities on most of Long Island are many times greater than vertical permeabilities. If most of the future pumpage is from the deeper aquifers, only a portion of the water recharged in the upper glacial aquifer will ultimately become available for water supply. The remainder will be lost to sea through the glacial aquifer.

However, if basins are located near mid-island, in the vicinity of Old Country Road in Nassau County, as much as 90% of the recharge will eventually reach the Magothy aquifer. Generally, the water supply pumped from the deeper aquifers can be greatly increased only by using recharge basins in this area.

CURRENT STATUS

The large number of existing basins on Long Island have demonstrated their capabilities in recharging storm water. Sewage in limited quantities from housing subdivisions has also been recharged through basins. Physical clogging of the soil particles or biological growth can reduce the infiltration rate although the problem is not as severe as with well recharge. Intermittant drying helps to restore the permeability and efficiency of the basins. The recharge basins on Long Island have fairly large infiltration capacities, and would certainly have the capacity to accept any foreseeable volume of renovated wastewater.

WATER QUALITY ASPECTS

Water quality is important to basin recharge since bacterial or algal growths will tend to clog the basin. The elimination of algal nutrients and organics plus chlorination will help to control these organisms. Higher levels of particulate matter can be recharged through basins than through wells. However, the water to be recharged should be of as high a quality as possible since it will eventually enter the water supply. Removal of total dissolved solids is not necessary because inorganics, per se, do not constitute a health problem. It may be desirable to add inorganic removal at a later time to prevent build-up in the groundwater. Some dilution of inorganics will undoubtedly take place since rainfall is being added to the recharged wastewater. Primarily, however, the cycle time between successive pumping of the same water is normally so long that build-up will be very slow. It may well prove more economical to demineralize the water pumped for supply instead of the wastewater to be recharged. This discussion does not apply to individual toxic inorganics such as lead and mercury. The most effective way of controlling these substances is by prohibiting their discharge into the sewage.

PROPOSED PROJECTS

Suffolk County is undertaking a basin recharge project at Twelve Pines Subdivision, Medford. The purpose of this study is to determine recharge rates using secondary sewage effluent. Water quality will be monitored to see if any changes take place. The existing secondary treatment plant will eventually be expanded to include denitrification. A series of recharge basins are being constructed to determine the recharge rates.

The above basin recharge project is primarily research oriented. On the other hand, Greeley and Hansen in CPWS-60[11] have developed projects for future water to be supplied in Nassau County. One of the projects suggested would pump renovated wastewater from the sewage treatment plants of Wantagh and Bay Park on the southern shore to the center of the island. The renovated water would be recharged in about 50 recharge basins and would increase the permissive yield of Nassau County by 94 MGD to 245 MGD. The feasibility of this method of increasing the available water depends on (1) a reduction in the cost of renovation and (2) an improvement in the reliability of the renovation processes. It is felt these two objectives could be accomplished with further research into tertiary treatment processes. Average cost for this recharge plan would be about $365/MG (ENR = 1400).[11] This includes tertiary treatment, transmission and recharge facilities.

PERSPECTIVE ON BASIN RECHARGE

Recharge of renovated wastewater on Long Island through existing storm basins is promising if treatment processes produce an acceptable water and it is economically feasible. Basin recharge would help maintain the esthetic and ecological aspects of Long Island's surface waters and brackish bays. There would also be an increase in water supply. The extent of this increase would depend on the location of the recharge basins and how much of the recharged water would permeate from the upper glacial aquifer to the Magothy and Jameco. The wastewater must be highly treated, although demineralization could be temporarily deferred.

RECHARGE INTO STREAM BEDS

OBJECTIVES

The primary objective of stream bed recharge is esthetic. The ecological requirement of maintaining fish life could also be important. Direct recreational (boating and swimming) and water supply benefits are very small. Primarily this method would serve to overcome some of the esthetic and ecological disadvantages of a lower water table without the necessity of raising the water table.

CURRENT STATUS

Little research has been conducted on the discharge of renovated wastewater to augment streamflow. No real problems are anticipated since very little new technology is required. Some water may infiltrate through the bottom of stream beds to recharge the groundwater, provided the water table is below the stream bed. Research is needed to determine exfiltration rates and if the stream bed would clog after a period of time. The extent of exfiltration would depend on the characteristics of the stream and the depth of the water table. Recharge rates must be carefully controlled to avoid high flows which could wash most organisms out of the channel.

WATER QUALITY ASPECTS

Since the water is going to be exposed to the public and various forms of plant and animal life, tertiary treatment is required. Nutrients should definitely be removed to prevent algal blooms in the streams. Organics should be kept to a minimum to decrease the BOD loading (a large BOD will lead to fish kills). BOD may be reduced to about 10 mg/l with activated carbon. It has been suggested that water be recharged to basins along stream banks to allow the water to filter through soil prior to reaching the stream.

PROPOSED PROJECTS

Holzmacher, McLendon and Murrell have developed a project proposal[12] for recharge to Carll's River and Sampawam's Creek in Suffolk County. The project would be carried out in five phases, beginning with data collection and proceeding through construction of full-scale treatment and recharge facilities. Renovated wastewater will be pumped to Belmont Lake to augment flows through the State Park. Costs are estimated for the first phase only. No timetable for development is included since the need for recharge depends on many other variables, such as sewer construction.

PERSPECTIVE ON STREAM BED RECHARGE

Flow augmentation through stream bed recharge is desirable primarily for esthetic and ecological reasons. There would be little benefit to the water supply except for some possible exfiltration through the bed. The recharged water would have to be highly treated to delay eutrophication. The technology to accomplish this type of recharge is currently available.

RECHARGE BY SPRAY IRRIGATION

OBJECTIVE

Spray irrigation is primarily a method of wastewater treatment and disposal. Its potential as a method of recharge is somewhat limited. The effect of spray irrigation on the groundwater would be similar to recharge by basins. The major benefit would be higher groundwater tables which would enhance the esthetic and ecological considerations. The water supply would benefit mainly from the extra volume of water which percolates from the glacial downward into the Magothy and Jameco aquifers.

CURRENT STATUS

Research of spray irrigation has been carried out for a number of years at Pennsylvania State University, where secondary sewage effluent is sprayed on non-food crops. As the wastewater passes down through the biologically active soil zone, nutrients are removed by the plant life. Some of the water is lost by evapotranspiration while the remaining portion percolates downward recharging the groundwater. The application rates have to be closely controlled to give the plant life an opportunity to remove the nutrients. Since these rates are slow, extremely large land areas are required. At Pennsylvania State University about 130 acres are required to recharge 1 MGD.

Muskegon County, Michigan, is undertaking a spray-irrigation project to treat 43 MGD of the county's sewage. About 10,000 acres are required. In addition, a pond capable of holding sewage flows for 151 days is being constructed. It will be used to store wastewater from the winter months for use during the summer. Cold climates permit spray irrigation during the growing season only.

WATER QUALITY ASPECTS

Water delivered for spray irrigation has usually undergone secondary treatment. Beyond this, however, the quality of wastewater destined for spray irrigation is not particularly important. The soil, sometimes called a "living filter," provides tertiary treatment for the wastewater. Nutrients are taken up by plants, organics are decomposed by bacteria, and suspended solids are removed by the filtering action of the soil. Probably some enteric bacteria and viruses are also removed. Certain inorganics may be absorbed by the soil particles. Little absorption would be expected on Long Island, however, due to the sandy nature of the soil.

PROPOSED PROJECTS

The Town of Brookhaven and the Brookhaven Nation Laboratories are planning to irrigate 4 acres of land with about 94,000 gallons daily to determine the applicability of spray irrigation on Long Island. The project, which is research oriented, will probably start sometime in 1973.

PERSPECTIVE ON SPRAY IRRIGATION

Spray irrigation does not appear feasible for widespread use on Long Island. Extremely large land areas are required. A minimum of 65,000 acres (100 square miles) would be needed to treat 500 MGD. Land areas of this size are simply not available. There may be some limited possibilities for spray irrigation of small amounts of water on the eastern end of the island. The process may be applicable to use on sod farms. Beyond this, however, the prospect of spray irrigation solving the water supply problems of Long Island are nonexistent.

RECHARGE INTO INJECTION WELLS

OBJECTIVE

Well recharge can be used to accomplish all of the objectives of recharge. Shallow wells will increase streamflow, raise water levels and increase subsurface outflow. There will also be an increase in available water supply. Deep wells will also help to maintain groundwater levels and will substantially increase the amount of water which can be removed from the deeper Magothy aquifer. Deep wells are unique in that they provide the only means of directly recharging the deeper aquifers.

CURRENT STATUS

Recharge wells have been used for a number of years in southern California, on Long Island and in other areas around the world. Most water recharged on Long Island is spent cooling water.

Recharge of renovated wastewater is considerably more complicated than recharge of cooling water, however. Several contaminants in wastewater tend to clog the aquifer surrounding the well screen. A major research project under way at Bay Park in Nassau County is investigating the feasibility of recharging renovated wastewater into the Magothy. Preliminary results indicate that the Magothy can be recharged through the use of deep wells, but there are several clogging problems which must be resolved before the economic feasibility can be accurately determined.[4] Current treatment processes must be upgraded so that strict quality standards can be maintained. Major factors contributing to clogging are turbidity, compounds of iron and/or aluminum phosphate, and bacteria. It has not been determined to what extent each of these contribute to clogging.[22]

To be economically feasible, deep well injection must be able to proceed for long periods of time before the well must be redeveloped. The longest run at Bay Park to date is 33 days. A failure of the filtration equipment caused the aquifer to clog resulting in the relatively short test run. The causes of well clogging are known. However, until an effective means is found to eliminate these causes, the potential of well recharge cannot be accurately assessed.

The ability of shallow wells to recharge wastewater is unknown. It is generally believed that shallow wells will operate much better than deep wells, because of the greater permeability of the glacial aquifer. However, clogging will remain a potential problem, requiring the water to be highly treated.

WATER QUALITY ASPECTS

Water to be injected through wells must be of extremely high quality. All suspended matter must be removed. Air entrainment at Bay Park did not seem to hinder recharge, so most likely degasification can be omitted on Long Island. The treated water has to be chlorinated to prevent bacterial growth around the well. Additionally, certain inorganics such as iron and aluminum can contribute to clogging and might have to be controlled. Further research at Bay Park will help to define the potential clogging problems of some of these inorganics. Any treatment failure which allows a quantity of poorly treated water to be injected into the aquifer could cause a well to clog quickly. A high degree of treatment efficiency and reliability is needed for well recharge to operate successfully. These requirements cannot be fully realized at the present time.

The quality of the recharged water is important from a public health aspect because recharge wells may be located quite close to public supply wells. Considering the degree of treatment necessary for injection, however, little more needs to be done to ensure the potability of the water. Organic removal must be part of the renovation process. Viruses seem to be mostly removed as the water moves through the soil. Of prime importance is removal of nitrogen prior to recharge. The collection of nitrates in the groundwater from sewage discharges and from fertilizer application has already caused serious water quality problems on Long Island.

PROPOSED PROJECTS

Research projects involving deep well injection have been carried out at Riverhead and Bay Park on Long Island. Research at Bay Park is continuing. The results of these studies to this date have not been particularly encouraging. In view of this fact, there are no significant proposals for use of deep injection wells. There are plans to conduct more research on the performance of these wells. Real progress in deep injection well recharge must await the development of efficient and reliable wastewater renovation processes.

PERSPECTIVE ON RECHARGE INTO INJECTION WELLS

Depending on the depth and location of a recharge well, any of the water needs of Long Island can be met. This ranges from shallow wells to raise the water table in one area to deep wells to prevent salt water intrusion along the coast.

In general, the problem of clogging is more of a deterrent to use of deep injection wells than any public health consideration. As evidenced at Bay Park, there are several reasons for well blockage, but the degree of blockage attributable to each reason is unknown.

Recharging treated wastewater through deep injection wells will not see widespread use until the mechanical problems have been resolved. It appears that some time will be required to solve these problems. Recharge through shallow wells may be feasible. Additional research is needed to determine this feasibility.

FINDINGS AND CONCLUSIONS

1. It is necessary to develop a project proposal to explore indirect reuse by recharge and recycling as a possibility to meet the growing demand in Queens and Nassau County while maintaining the ecological, recreational and esthetic values on Long Island.

2. Four methods of groundwater recharge could be used on Long Island. These are:

   a. Basins - The primary benefits would be esthetic and ecological. Water supply would also be increased, but the magnitude would be less than the magnitude of recharge. Recharge through basins is technically feasible, however, it may be expensive. The permissive yield of Nassau County could be increased about 94 MGD through basin recharge at a cost of $365 per million gallons. No estimates are available for the rest of Long Island.

   b. Stream beds - The primary benefit is esthetic. Any increase in water supply would be very small. No detailed costs are available but they are expected to be high. The process is technically feasible but not not attractive.

   c. Spray irrigation - This is not feasible for widespread use on Long Island because of the large land area requirement.

   d. Injection wells - These can theoretically be used to satisfy any of the water needs of Long Island. However, more development work and research must be done before the potential of wells can be fully evaluated. They cannot now be considered an effective means of recharge.

RECOMMENDATION

The use of recharge in the development of Long Island's groundwater resource should be closely investigated. A project proposal should be developed using basin recharge to increase the permissive yield of Long Island. This proposal should determine the economic feasibility of recharge. Research should also begin to determine the feasibility of recharge using shallow wells.

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APPENDIX A

DESCRIPTIONS OF DESALTING AND TERTIARY PROCESSES

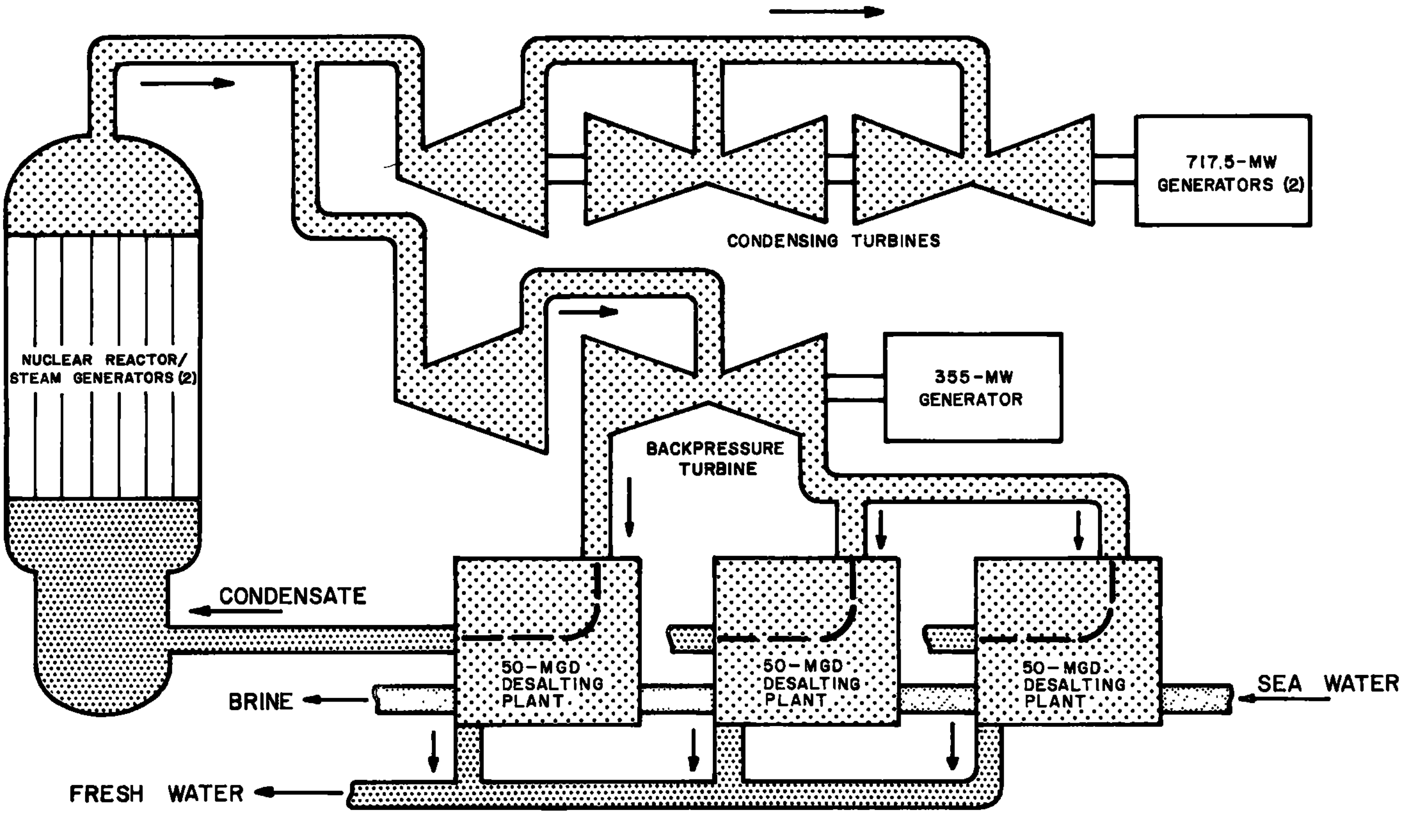

FIGURE A-1

DUAL PURPOSE DESALTING AND POWER PLANT

Plant shown above has been proposed for Southern California. Steam generated in two pressurized water reactors powers two 717.5 mega-watt condensing turbines and one 355 mega-watt backpressure unit. Exhaust steam from the latter passes to sea water heaters in a multi-stage flash-distillation plant rated at 150 MGD.

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*Figures A-1 through A-5 were taken from "Water", a special report published by Power, 330 W. 42nd Street, New York, New York, 10036, June 1966.

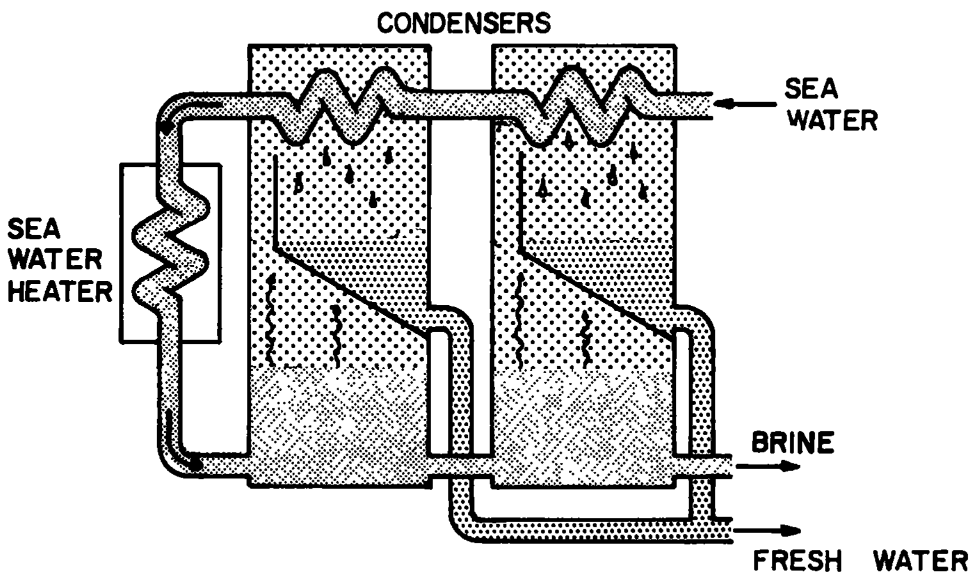

FIGURE A-2

FLASH DISTILLATION

Flash Distillation appears most commonly in multi-stage (MSF) form. Incoming sea water, heated to about 250 F, passes into a flash chamber pressurized just below water's boiling point. In this reduced pressure, some water flashes to vapor, which condenses on sea water-cooled tubes and is collected as fresh water. Remaining brine passes through a series of similar chambers at successively lower pressures.

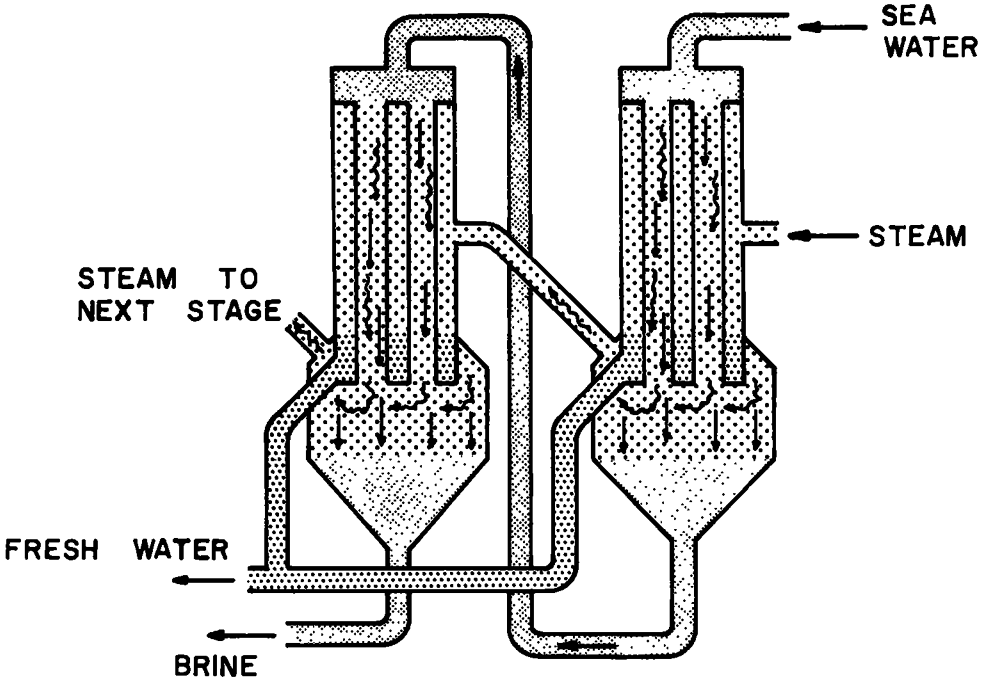

FIGURE A-3

LONG-TUBE VERTICAL

Long-tube vertical design replaces vacuum chamber in each stage with vertical tube bundles. Evaporation occurs as hot sea water trickles down tubes; vapor so generated goes on to heat the incoming brine in a subsequent stage. Thus sea water boils on the inside surface of each tube while fresh water condenses on outside. Maximum practical water temperature, as in MSF process, is 250°F; pre-treatment can raise this.

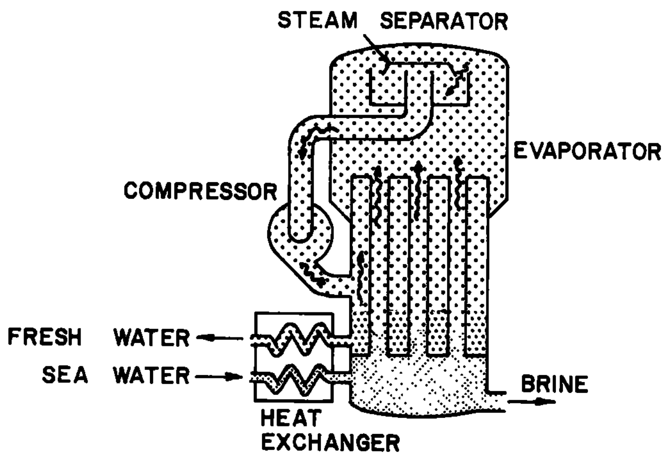

FIGURE A-4

VAPOR COMPRESSION

Vapor compression distillation is a third version of the basic process used in the multistage and long-tube vertical systems. Vapor from the sea water is compressed and returned to the evaporator, where it condenses at its new, higher temperature and, in doing so, gives up sufficient heat to boil more sea water.

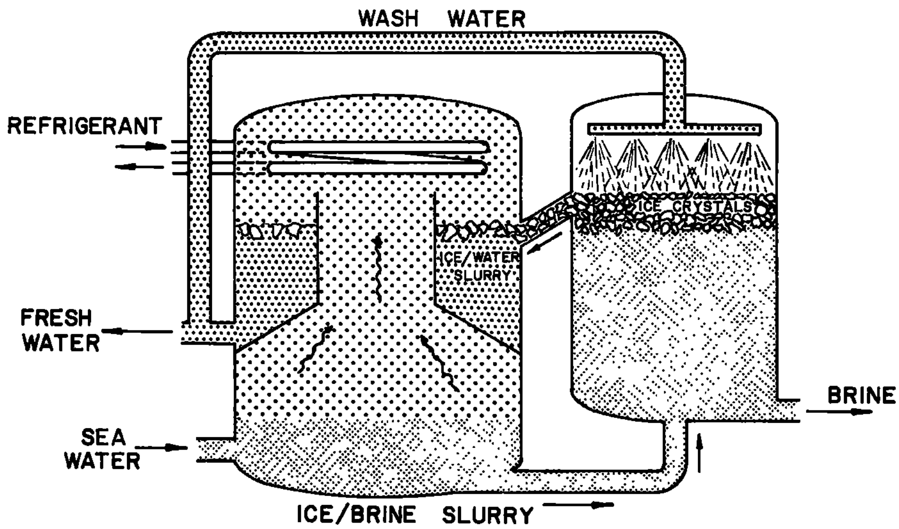

FIGURE A-5

VACUUM FREEZING

Chilled sea water enters a freezing chamber held at a low pressure (3.5-mm mercury). Part of the water flashes into vapor, removing heat from the remainder to do so. Since this is already close to its freezing point, ice crystals form. Washed of brine coating, they yield fresh water.

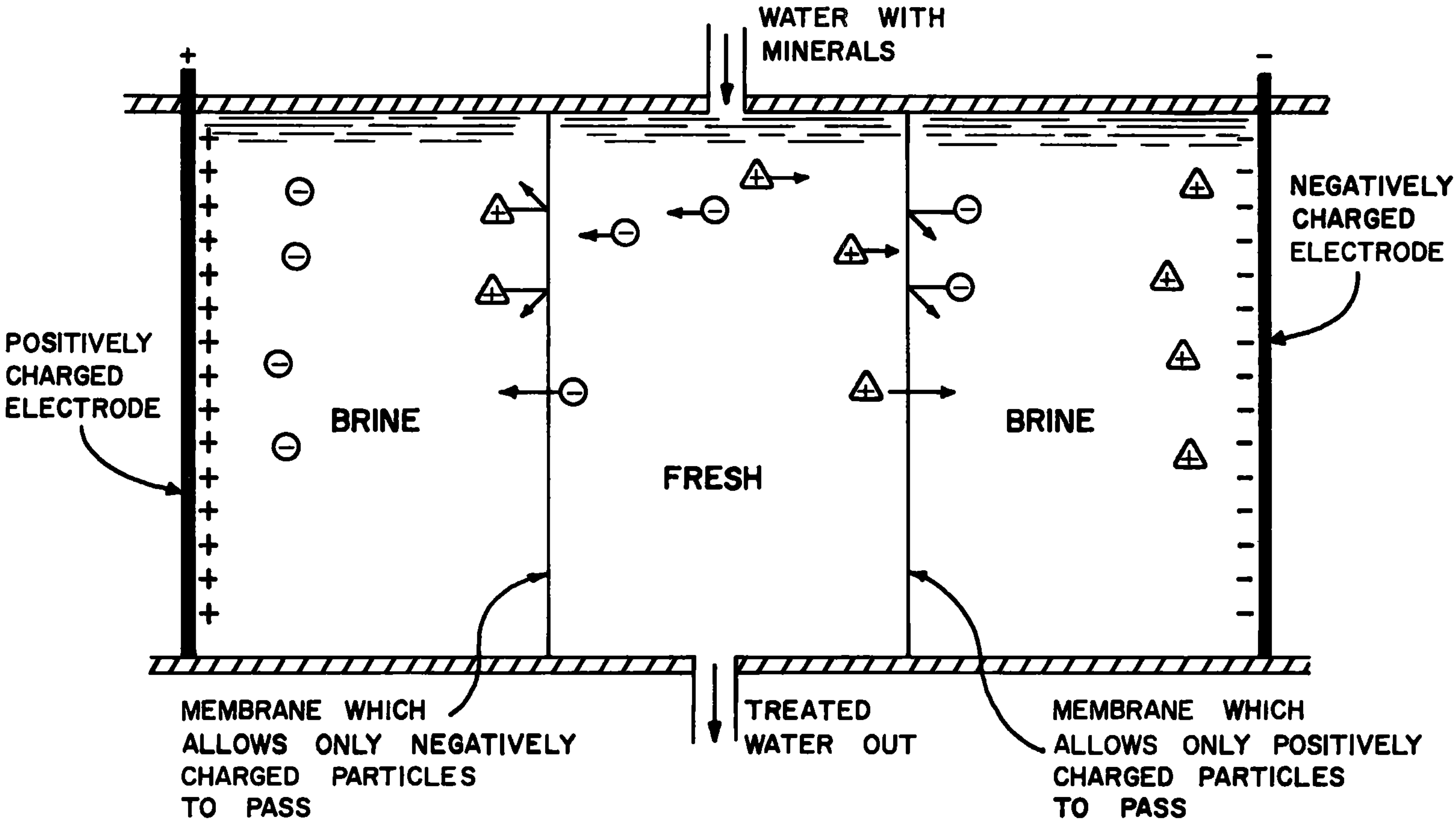

FIGURE A-6

ELECTRODIALYSIS

Minerals or inorganics dissolved in water usually form either positively or negatively charged particles. In a simple electrodialysis unit, a tank is divided into three compartments by two membranes. One membrane is made of a substance which will let only negatively charged particles pass, while the other will transmit only positively charged particles. When a direct electrical current is applied to electrodes at each end of the tank, the negative inorganic particles travel toward the positive electrode and the positive particles toward the negative electrode (opposite charges attract), passing through the respective membranes. The brine at each end contains both positive and negative particles. The membranes, however, keep the particles repelled by the electrode in that compartment from entering the middle compartment. Fresh water which is reduced in mineral content results in the center.

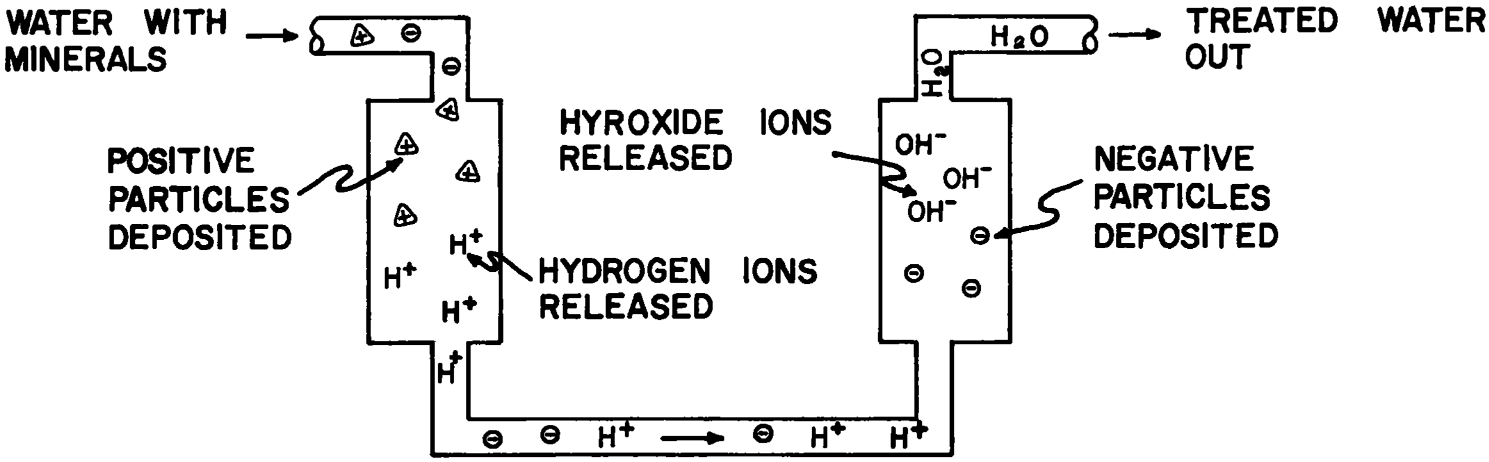

FIGURE A-7

<u>ION EXCHANGE</u>

A water molecule is composed of two chemical units, a positively charged hydrogen ion (H^+) and a negatively charged hydroxide ion (OH^-). When these two ions react, water, or H_2O, is formed, as shown

$$H^+ + OH^- \longrightarrow H_2O$$

In ion exchange, the positively and negatively charged inorganic particles dissolved in water are replaced by H^+ and OH^-, thereby forming new molecules of water in place of the original dissolved material.

In the above diagram, water containing positively and negatively charged dissolved minerals enters from the left. In the first chamber, which is rich in hydrogen ions, positive minerals are swapped in a chemical reaction for H^+. The water containing H^+ and genative mineral particles continues to the second chamber to be replaced by hydroxide ions, OH^-. The H^+ and OH^- remaining, then combine to form H_2O. The charged mineral particles remain part of the material in the chambers and do not re-enter the water.

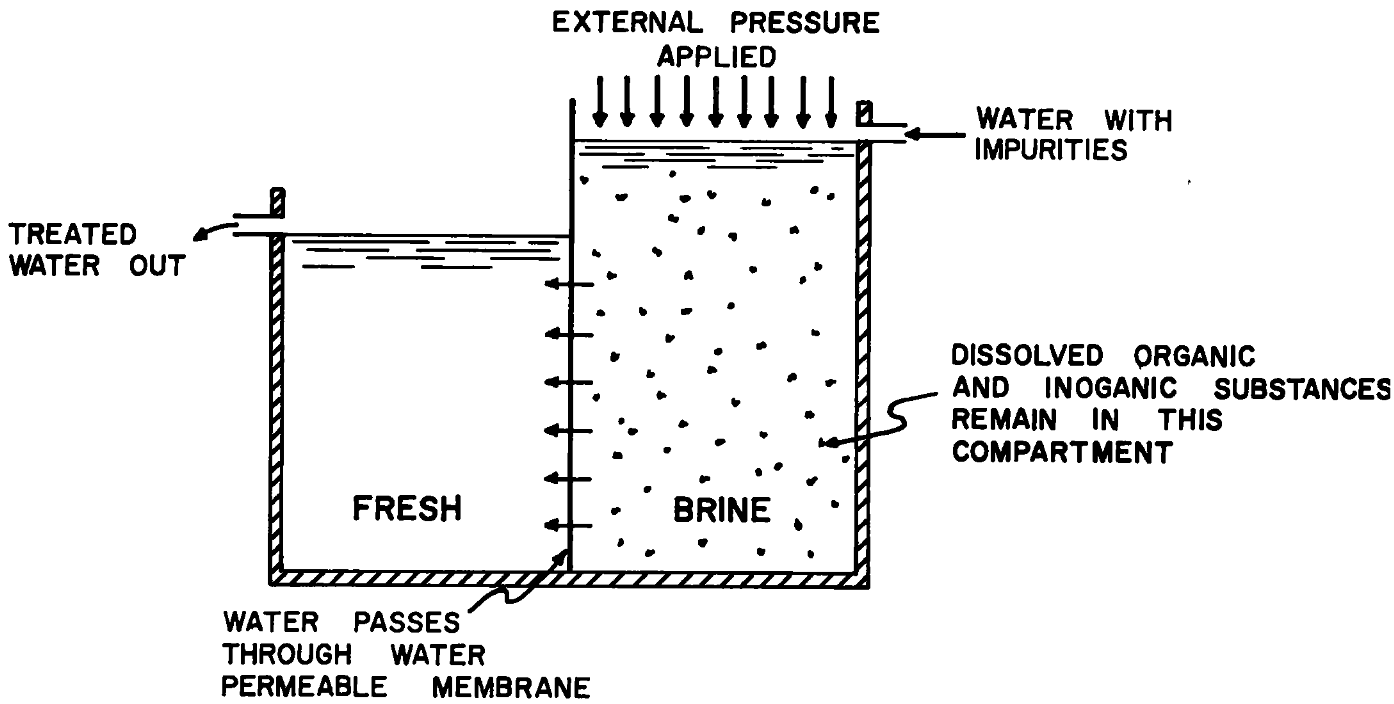

FIGURE A-8

REVERSE OSMOSIS

Water containing dissolved inorganics and/or organics enters the compartment on the right. Pressure is applied to this water forcing it through the membrane into the compartment on the left. This membrane has the property of preventing passage of dissolved minerals and organics while allowing the passage of the pure water. The dissolved particles do not pass through the membrane and in a sense are "screened out".

Dissolved particles tend to collect on the surface of the membrane causing it to foul. The more impurities the water contains, the quicker the membranes foul, resulting in higher treatment costs. This is why reverse osmosis is more expensive as a single-step, total removal process (removing all types of impurities) than when it is used to remove inorganics only.

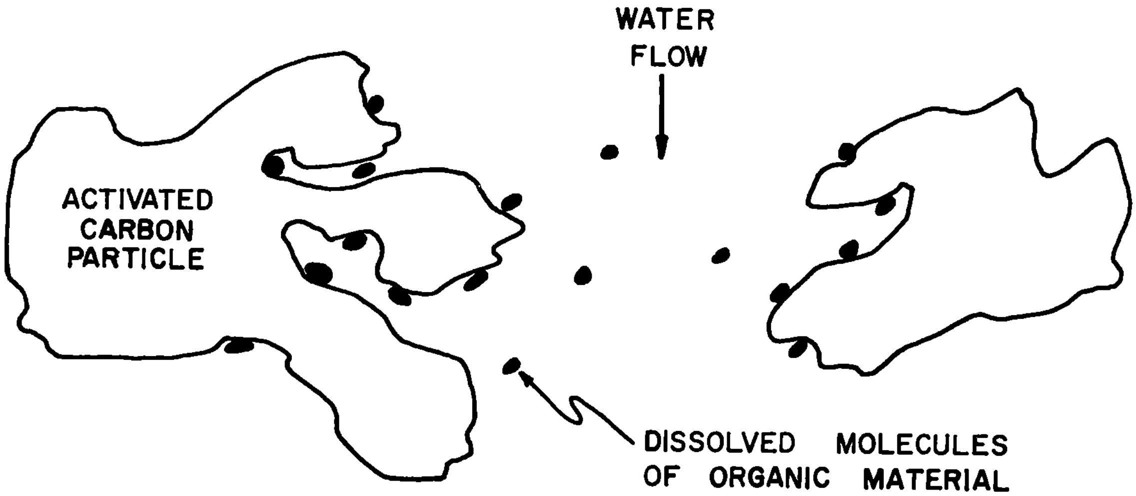

FIGURE A-9

ACTIVATED CARBON

Activated carbon particles, made from chunks of carbon or coal, have very irregular surfaces containing many cracks and fissures. The particles are normally very small, hence the above diagram is magnified many times. As water moves through columns filled with activated carbon particles, dissolved organic molecules are attracted to the surface of the particles. The organic molecules adhere to the carbon once they come into contact with its surface. This is known as adsorption. Because of the numerous fissures, large numbers of molecules can be adsorbed before the carbon becomes saturated.

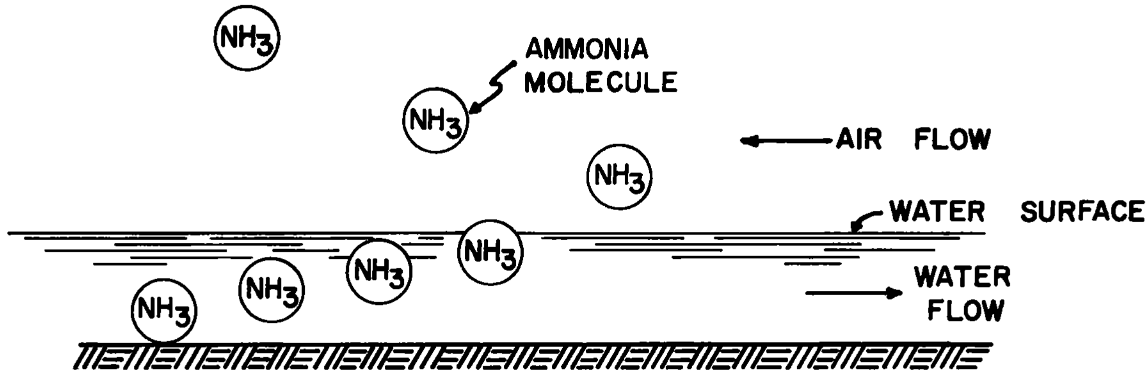

FIGURE A-10

AIR STRIPPING

Ammonia, with chemical formula NH_3, is easily dissolved in water. When a thin layer of water is exposed to large volumes of air moving past, the ammonia leaves the water and enters the air, acting like any other gas in the atmosphere. The air containing ammonia moves away from the water carrying the ammonia with it.

APPENDIX B

EPA POLICY STATEMENT ON DIRECT REUSE

ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

Mr. Robert D. Hennigan, P.E.
Executive Director
Temporary State Commission
on the Water Supply Needs
of Southeastern New York
30 Wall Street
New York, N. Y. 10005

Dear Mr. Hennigan:

This is in reply to your letter of September 26, 1972 asking for a statement from us on the draft report "Proposal for Augmenting New York City Water Supply Through Waste Water Purification and Reuse" dated August 1965 and marked "Administrative-Confidential." This report proposed a direct interconnection between the Hunt's Point Waste Treatment Plant and the city water system.

According to Science Advisor Hornig in testimony before the Senate Interior and Insular Affairs Committee on September 8, 1965, the subject report was prepared at his request.

However, it is unfortunate that this draft report ever received widespread distribution in New York State because it was never cleared by the Department of Health, Education, and Welfare; the reason for non-clearance being that insufficient attention had been given to health aspects.

Since our transfer to the Environmental Protection Agency, additional attention has been given to this subject and a policy statement, copy attached, was promulgated on July 7, 1972. It may be noted in point 3 of this statement that "EPA does not currently support the direct interconnection of wastewater reclamation plants with municipal water treatment plants." Consequently we would still find the 1965 draft report unacceptable.

Sincerely yours,

James H. McDermott

James H. McDermott, P.E.
Director
Water Supply Division

Attachment

EPA POLICY STATEMENT ON WATER REUSE

The demand for water is increasing both through population growth and changing life styles, while the supply of water from nature remains basically constant from year to year. This is not to imply that we are or will shortly be out of water, although water shortages are of great concern in some regions and indirect reuse has been common for generations. We must recognize the need to use and reuse wastewater. Therefore,

1. EPA supports and encourages the continued development and practice of successive wastewater reclamation, reuse, recycling and recharge as a major element in water resource management, providing the reclamation systems are designed and operated so as to avoid health hazards to the people or damage to the environment.

2. In particular, EPA recognizes and supports the potential for wastewater reuse in agriculture, industrial, municipal, recreational and groundwater recharge applications.

3. EPA does not currently support the direct interconnection of wastewater reclamation plants with municipal water treatment plants. The potable use of renovated wastewaters blended with other acceptable supplies in reservoirs may be employed once research and demonstration has shown that it can be done without hazard to health. EPA believes that other factors must also receive consideration, such as the ecological impact of various alternatives, quality of available sources, and economics.

4. EPA will continue to support reuse research and demonstration projects including procedures for the rapid identification and removal of viruses and organics, epidemiological and toxicological analyses of effects, advanced waste and drinking water treatment process design and operation, development of water quality requirements for various reuse opportunities, and cost-effectiveness studies.

WATER REUSE

Background

While indirect and delayed reuse of water has many accepted applications, the direct application of measures to reuse wastewaters for constructive purposes presents both new opportunities and new problems. Direct reuse is currently being conducted in a number of places for specific purposes; in fact, California reported in 1969 over 200 non-potable reuse situations. Reuse is being applied for a number of purposes, including industrial use for cooling purposes, for groundwater recharge to prevent salt water intrusion in coastal areas; as a source for recreational waters; for irrigation and other agricultural uses, not involving direct contact with food surfaces; and for other uses. An annex is included for definition of direct and indirect reuse and discussion of the differences related thereto.

The potential for water reuse, as a tool in broad water resources and water quality planning, is many times greater than current practice and should be routinely considered and developed to meet non-potable demands. As could be expected, activity with regard to reuse appears to be much intensified in water-short areas of the country, for instance in the arid West. The Water Resources Council (WRC) report, "The Nation's Water Resources, 1968" cites water shortage problems in 9 basins--Arkansas-White-Red; Texas-Gulf; Rio Grande; Upper Colorado; Souris-Red-Rainy; Missouri; Lower Colorado; Great Basin; and California--and pointedly shows that these problems will worsen by 2020 unless remedial measures are applied.

In addition to reuse of wastewaters, attention is being given to weather modification, desalination, water conservation, interbasin transfer, tapping of the geothermal deep-water reservoirs and other approaches to conserve existing as well as tap new sources. Reuse should be considered in the light of water quality, environmental, ecological, and economic aspects as well as the public health aspects; it should provide a vital link in meeting needs in water short areas.

Reuse Application and Public Health Problems

Taking a national view of fresh water demands, it may be seen from the 1968 WRC report that for 2020, electric power (cooling water) will be first in demand (410 BGD); self-supplied industrial, second (210 BGD); irrigation, third (161 BGD); with minor residue demands for livestock and rural domestic. Logically, one would expect that priorities for reuse would pattern after demand with electric power (cooling) first, industrial second, etc. Such a pattern of application would ideally suit health protection-water quality relationships since cooling and most industrial uses would present low health risks; irrigation for some crops would be potentially hazardous, but not for others; and municipal uses would offer the greatest human contact and the largest potential danger.

The problem may not be handled so simply on gross utilization terms since each call for water reuse will be situational, depending on geographic location, climate, public attitudes, the availability of wastewater sources and of potential water users, etc. One community may be non-conservative in utilizing its fresh waters and be willing to treat and recycle wastewaters in order to continue its easy-water practices while another community with a similar policy and an abundant supply of cheap water may be unwilling to treat and recycle wastewater just to conserve water for use by others--for instance for irrigation or municipal purposes elsewhere. In one case, a needy municipality may be in a position to utilize industrial wastewaters and in another case a needy industry may be situated so as to use municipal wastewaters. In any event the technology is available for the treatment and reuse of many wastewaters for many purposes and such reuse should be broadly considered in the management of water resources.

Public health problems do occur and require attention as follows:

1. Industrial: The reuse of water by industry should be encouraged where it is technically and economically feasible. Quality needs for industrial uses vary so widely that it is not possible to generalize on this subject; however, except for food processing industries, they are usually lower than drinking water requirements.

2. Groundwater Recharge: Groundwater recharge can be used to raise or maintain the level of groundwater and/or to prevent the intrusion of salt water. For most recharge applications through spreading and percolation of reuse waters on the surface, quality requirements for health protection would be enhanced by natural filtering porcesses. However, percolation into a shallow basin used for drinking water supply should receive careful attention and the recharge of reuse water by subsurface injection should not be implemented without strict controls and a clear demonstration that such disposal will not harm present or potential subsurface water supplies or otherwise damage the environment.

3. Recreation: Indirect reuse of water for primary contact recreational purposes is clearly recognized in the section on recreational uses in Water Quality Criteria[1] by way of the recommended limits for fecal coliform organisms and the recommendation that sanitary surveys be conducted to determine the degree of threat of pathogens from specific sources.

   The hazards associated with direct contact recreation in waters receiving inadequately treated waste discharges are chiefly biological and are usually associated with a transmission of infectious diseases that may enter the body through the mouth or nasal passages or other portals such as the eyes, and certain areas of the skin. Numerous examples may be given of both direct and indirect use of treated wastewaters for recreational purposes and this appears to be a valid practice where health requirements can be met. However, much remains to be known about the health relationships of water quality and recreational use. For example, water high in nutrients may serve as a culture for pathogenic bacteria. Further research and epidemiological investigations into water quality and health relationships are urgently needed.

4. Irrigation: The reuse of waters for irrigation is and should be a satisfactory mode of reuse. Water quality requirements for crop protection relate primarily to salinity and toxic compounds. For irrigation of non-food or shelled-food crops health considerations would be minimal but for irrigation of other food crops or of pasturage for food-animals, the hazards are significant unless the water is adequately treated. Much study and development of safeguards should precede this latter use.

5. Municipal: The concurrent use of the Nation's rivers and lakes for both water supply and waste disposal has been practiced for many years in many areas of the country. It is estimated that 50% of the Nation's population now derives their water supply from surface sources which have also received a variety of industrial wastes, untreated sewage, urban runoff and effluent from a variety of sewage treatment plants. Public health officials have relied upon time of travel or storage and treatment to protect the public against infectious diseases and toxic substances. Water quality standards and treatment requirements applicable to surface sources used for water supply have permitted the discharge of relatively high quantities of wastes. The continuing development of new advanced wastewater treatment technologies and implementation of new standards will necessitate a reappraisal of historical philosophies.

   Indirect reuse for municipal public water supply is a fact of life; however, direct reuse is a new matter requiring careful research and investigation before introduction. Currently, there is insufficient data to support safety of direct interconnection of wastewater reclamation plants into municipal water supplies. However, the direct connection of municipal renovated water to supply industrial water needs is desirable and should be exploited where practical.

Health problems in a direct interconnection or in a recycling situation relate to viruses, bacterial build-up, chemical build-up, the possibility of accidental spills or sabotage and a record of questionable reliability in the operation of wastewater treatment plants. Viruses are difficult to identify and measure and are more resistant to disinfection than bacteria. Carbon columns and other possible advanced waste treatment elements may harbor bacteria or their metabolites and contribute to the development of unhealthful levels of bacteria in a recycling situation.

The direct introduction of chemicals from a waste-stream and their build-up through potable system-waste system recycling can present increased long-term chronic hazards, presently undefined. Accidental spills or sabotage present an acute threat which cannot be disregarded, as anyone can throw anything down the drain. Because of these, even if other objectionable problems were solved, some system of holding and dilution reservoirs may inevitably need to be provided between the reclamation plant and the potable water intake together with biological and chemical monitoring. With regard to the reliability of reclamation plant operation, studies[2] in California have shown that 60% of wastewater treatment plants studied had some breakdown during the year. Observations of engineers and others confirm that reliability is a common problem in wastewater treatment plants; safeguards must be provided to prevent the introduction of non-treated or poorly treated wastes into a potable water system.

Conclusions

1. The purposeful reuse of treated wastewaters has a large potential in helping to meet water supply needs. Expansion of reuse as a tool of water quality and water resources management should be encouraged as long as measures are taken to protect the public health.

2. We do not have the knowledge to support the direct interconnection of wastewater reclamation plants into municipal water supplies at this time. The potable use of renovated wastewaters blended with other acceptable supplies in reservoirs may be employed once research and demonstration has shown that all of the following conditions would be met:

   a) protection from hazards to health

   b) offers higher quality than available conventional sources

   c) results in less adverse ecological impact than conventional alternatives

   d) is tested and supplied using completely dependable chemical and biological control technology

   e) is more economical than conventional sources

   f) is approved by cognizant public health authorities

3. An accelerated research and demonstration program is vitally needed to:

   Develop basic information and remedial measures with respect to viruses, bacteria, chemical build-ups, toxicological aspects and other health problems. Develop criteria and standards to assure health protection in connection with reuse.

   Upgrade the treatment process design and operation so as to assure continuously safe service to the public. Provide economic and other analyses to facilitate the planning and design of effective regional solutions to problems of water-shortage and water quality.

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[1] Water Quality Criteria, Report of the National Technical Advisory Committee to the Secretary of the Interior, April 1, 1968.

[2] Ongerth, H. J., Jopling, W. F., and Deaner, D. G., Fitness Needs for Wastewater Reclamation Plants, J. American Water Works Assn., Oct., 1971.

ANNEX: DEFINITIONS AND DISCUSSION OF DIFFERENCES FOR DIRECT AND INDIRECT REUSE

Definitions are derived from a report of the National Water Commission, "Wastewater Reuse," by Jerome Gavis, July 1971, as follows:

1. Direct Reuse: is the direct routing of treated wastewater effluents to the point of use.

2. Indirect Reuse: is the discharge of treated wastewater where it is subjected to natural purification processes and dilution before being withdrawn for use.

Differences in the two types of reuse that must be considered in any drinking water application are as follows:

1. Direct reuse is more vulnerable to sabotage, operational failure and the accidental spill of toxic or hazardous substances into the water-wastewater system. The provision of fail-safe equipment, processes and holding reservoirs may be necessary to meet this problem.

2. Direct reuse allows no margin for error in the destruction of pathogenic viruses, bacteria and other microorganisms.

3. Direct reuse could result in the buildup of trace substances to many times their usual concentration; depending on the degree of reuse and the efficiency of treatment, the concentration factor could run up to nine times.

Many of the factors influencing direct reuse may come into play for indirect reuse. If the time and dilution factors before indirect reuse are small, the impacts of dilution and natural purification may be minimal. Yet the question of what time and dilution factors are adequate cannot be answered on the basis of today's knowledge. Research to acquire new basic knowledge and common sense in the application of today's limited knowledge is essential. Also, it is essential that each reuse situation be treated on an individual basis, taking into account all factors.